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BOTTOM STRUCTURE OF THE SEA OF JAPAN, FROM THE "VITYAZ" EXPEDITION DATA

by

I. B. Andreyeva and G. B. Udintsev

INTRODUCTION

In recent years, marine geology has made extensive use of seismo-acoustic methods which are based on analysis of reflected and refracted waves. These waves, generated by an explosive charge, are propagated both by the water and by the material of the sea bottom. They are reflected back from the bottom sediments and from inter-layer surfaces and are refracted back from those surfaces. The initial application of seismic methods to oil prospecting in shallow coastal areas has led to the development of seismic techniques for the study of sea and ocean bottoms at greater depths [8, 11, 13]. Considerable information has now been accumulated on the structure of the earth's crust and the distribution of unconsolidated sediments throughout the Atlantic and parts of the Pacific and Indian Oceans [6, 10, 18]. Least known are the structure of the continental slope and that of the unconsolidated bottom deposits.

The great value of the successful application of seismo-acoustic methods to marine geology has stimulated the development of equipment and techniques for this purpose at the Oceanology Institute, Academy of Sciences, U.S.S.R., in collaboration with its Acoustical Institute. Beginning with 1951, apparatuses have been perfected, and studies undertaken in the Black and Caspian Seas, and in the Pacific. The first significant attempt at seismo-acoustic exploration, made by the 19th "Vityaz" expedition in the northwestern Pacific, did not take place until 1954 [7]. Explorations on a smaller scale continued in the Pacific, by the 22nd "Vityaz" expedition; and in Antarctic waters and the Indian Ocean, by the 1st and 2nd "Ob'" expeditions.

In conjunction with its seismo-acoustic work, the Oceanology Institute carried on geologic studies, particularly of the Sea of Japan bottom. The bottom topography was investigated by echo sounding; bottom samples were taken, both surface and columnar;

and a study was made of suspended fractions, the source material for the bottom sediments. As a result of these studies, bathymetric and geomorphologic maps have been constructed, as well as bottom-deposit maps, and the general features of the Quaternary history of those seas outlined. These data gave the first approximation of the Sea of Japan tectonics, and of the relationship between its larger features of bottom relief as a structure expression, and the land structures [3, 4, 5]. The submerged rims of the continents were fairly well delineated, thus accurately locating the continental slope, as well as the structural features of that belt which surrounds the Sea of Japan depression [1]. In this connection, the data on the thickness of the Japan Sea bottom deposits, on the underlying basement relief, and on the structure of the earth's crust at depth, became of considerable interest. Such data were obtained in April 1957 by the 22nd "Vityaz" expedition. They are set forth in this paper.

I. CONDITIONS AND METHOD OF INVESTIGATIONS

The Sea of Japan depression is located in the transitional continental slope zone of East Asia. Its flat bottom represents the ultimate base of deep sea deposition, the formation and development of which has been influenced to a considerable degree by the sediment redistribution brought about by density currents and by the slower and more permanent suspension bottom currents. To the northwest, the depression-bottom plain borders on the steep continental slope; to the southeast, on the Yamato submarine plateau which is an important diastrophic complex formed by the intersection of two island arcs, the Kuriles-Kamchatka and the Ryukyu. Still farther southeast, the Sea of Japan depression borders on the mountain structures of the Japan island arc, also within the continental slope transition zone.

The investigations were made along two cross sections of the flat western part of the Sea of Japan bottom (Fig. 1). The cross

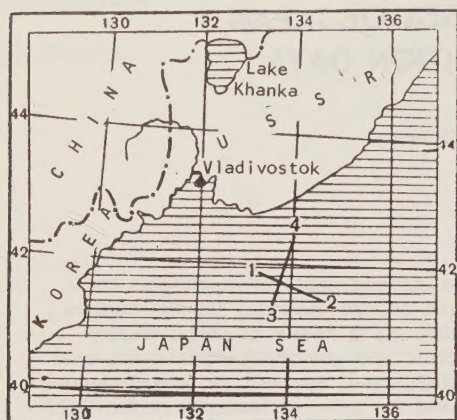


FIGURE 1. Location of seismo-acoustic cross sections.

sections are normal to each other, oriented approximately with and across the continental slope trend. The depth of the working area, in the order of 3550 m, is typical for the flat bottom of the Sea of Japan. Only in the northern segment of the second cross section were shallower depths of about 3300 m

observed, associated with a slight uplift apparently of tectonic origin.

The work was carried out by conventional

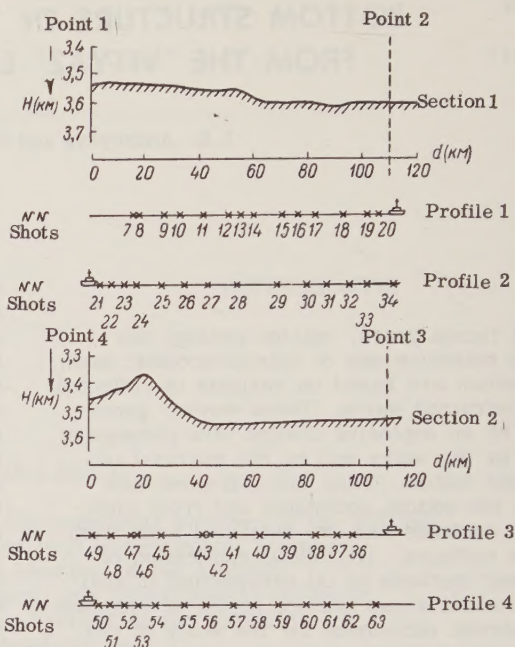


FIGURE 2. Bottom relief along sections 1 and 2, and shot points distribution along the four seismo-acoustic profiles.

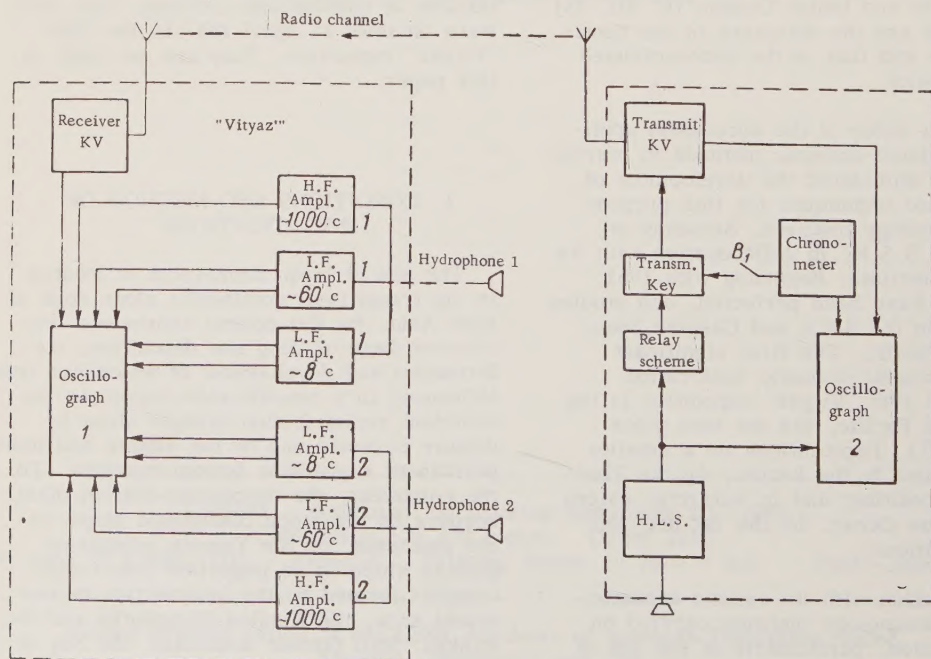


FIGURE 3. Diagram of shot recording.

method, using two ships. One of them, the auxiliary, rode the cross section, setting off TNT explosions every 5 to 15 km; while the other, the "Vityaz," remained at the initial or terminal point of the cross section and received the acoustic signals from each shot. Both sections were shot in both directions, in order to obtain data for reverse time-distance plots, and to determine the dip of the formation boundaries. The maximum length of each cross section was about 110 km (70 miles).

Some 63 shots were fired, the size of the shot varying from 25 to 130 kg, depending on the distance. Distances between the shot and the recording points were only approximately determined during the work; the exact data were obtained from the direct-wave records. The distribution of shot points along the profile is given in Fig. 2 which also shows the bottom relief along it (echo-sounding data). Hydrological measurements were made at the recording points. They revealed an area of increased sound velocity near the sea surface. The sound velocity, averaged vertically from surface to bottom [12], i.e.,

$$c = \frac{H}{\int_0^H \frac{dh}{c_h}} \quad [1]$$

was about 1477 m/sec (where H is the depth of sea; c_h is the sound velocity at depth h).

The work was carried on under favorable weather, the sea, as a rule, not above 1 to 2 points.

The shot recorder diagram is given in Fig. 3. The auxiliary was equipped only for the shot timing and its broadcasting to the "Vityaz." The acoustic waves were recorded on the "Vityaz" by two identical

hydrophones. Their hanging had been done according to R. Raitt's recommendations [21] which obtained a reliable reception of weak signals.

2. RECORDING OF SOUND WAVES AND THEIR PROPAGATION FEATURES

Since the explosive charges were adequate, the frequency composition of a direct wave and of the signals reflected from the bottom, remained practically the same, as much as distances of several tens of kilometers (Fig. 4). This perceptibly hampered the separation of the direct water wave from the complex of recorded signals. Initial deciphering of the records was accomplished on the basis of graphic correlation of time intervals between the arrival of the direct and reflected waves with their respective calculated values. As an example, Fig. 5 gives the results of correlation along profile 4.¹ Distances to shot point are plotted along the horizontal axis; and the calculated values of differences (Δn) in the arrivals of direct (D) and reflected (R_n) waves, along the vertical axis.

In the maze of arrivals, experimentally obtained for each shot, there was but one place on the graph where the experimental and the calculated points practically coincided, thereby making possible, in nearly all cases, a reliable identification of all arrivals.

Thereafter, the absolute propagation time was calculated for all waves -- direct, reflected, and refracted -- as recorded for each shot. Two shots, Nos. 35 and 44,

¹ By "profile" a single run of the cross section is meant.

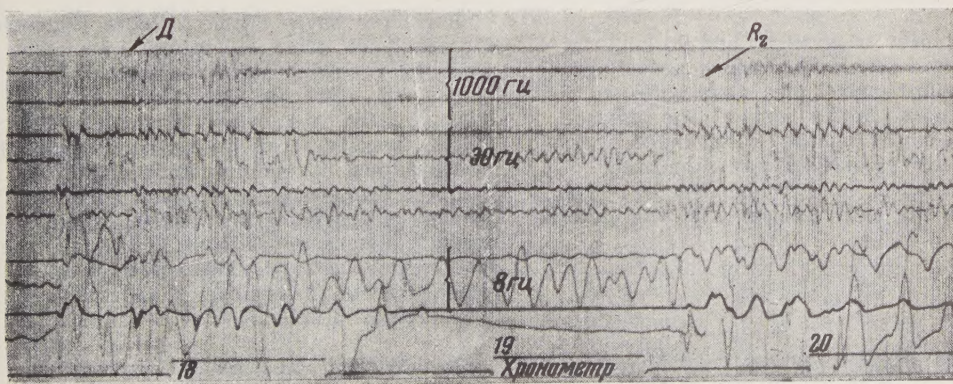


FIGURE 4. Graph of direct and reflected waves. Shot 36

were not recorded by the "Vityaz" because of an equipment breakdown and were dropped. For technical reasons, the shooting time for 12 shots was not recorded, making their processing difficult. If the distances between shot and hydrophone were not great, and the reflected waves contained sharp high-quality components (as in shots Nos. 17, 20, 24, and 38 to 41), the missing values were found from time differences in the arrival of direct and reflected waves. The error of these calculations did not exceed 0.05 sec. In five other instances, shots Nos. 42 and 45 to 48, the distance was only approximately determined, with errors as much as 0.5 sec.

The distance, shot point to hydrophone (d), was calculated from the propagation time for direct wave D and the velocity in the sound channel, $c_0 = 1,450$ km/sec.

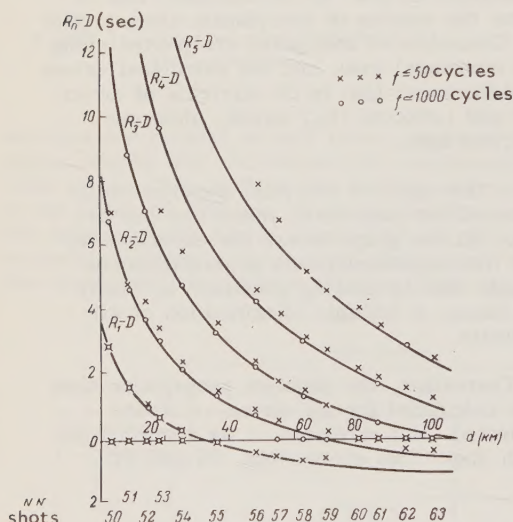


FIGURE 5. Arrivals of direct and reflected waves of different frequency.

At distances of about 50 and 90 km, the arrivals of a direct wave were camouflaged by an earlier arrival of a wave reflected once or twice, by the bottom. The distance, shot point to hydrophone, along these stretches of the profile, was calculated from the arrival time of high-frequency components of the reflected wave, by a simple formula:

$$d = c \sqrt{R_n^2 - \left(\frac{2nH_{cp}}{c}\right)^2}, \quad [2]$$

where c is average vertical velocity (see formula [1]), n is multiplicity factor for reflected wave, R_n is propagation time for reflected wave, H_{av} is average sea depth

for the given area.

After corrections appropriate to the area, the calculation error was found to be in the order of 0.005 sec. The results are given in Tables 1 and 2.

A characteristic feature of the reflected waves' propagation is a lagging of middle- and low-frequency components behind the high-frequency arrivals. As seen in Fig. 5, the arrivals of high-frequency components agree best with the theoretical data as obtained from the depths registered by the echo soundings. The lagging of the lower-frequency components (as much as tens of cycles) may be explained by their penetration to some distance into the uppermost bottom layers.

Another feature of the reflected-waves propagation is a dampening of signals with distance and their final extinction, for waves reflected once or twice. For once-reflected waves, this occurs at the distances, shot point to hydrophone, of about 50 km; for twice-reflected waves, at 90 km, and is easily explained by a simple theory of sound-waves propagation in the sea [2].

Of note is the decrease in the maximum observed multiplicity factor for reflections, with a decrease of the distance, shot point to hydrophone; apparently, this effect is connected with the decrease in the reflection coefficient for small angles of incidence of the sound ray to the bottom.

At the shot point to hydrophone distances of more than 60 to 70 km, the high-frequency components of the reflected signals weaken, then fully disappear. This is primarily observed at a high multiplicity factor of the reflected signals, which is easily explained by pronounced fading of the high-frequency components in the uppermost bottom layers.

Refracted waves (Table 2) were registered for nearly all shots, 10 to 110 km distant from the receiving point. At shorter distances, the refracted waves were swamped by an earlier direct wave; at greater distances, the refracted wave signal was much weakened and commonly poorly discernible over the background noise. The maximum number of sharp signals were observed at medium distances, 40 to 50 km, where the total number of registered refracted waves reached 10 to 15 (not over 8 arrivals are registered in Table 2).

It should be noted that the propagation conditions for refracted waves were substantially worse along cross section 1-2 than along 3-4, which apparently is con-

Table 1

Arrival times for direct and reflected waves (in sec)

Shots No.	d (km)	D	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
7	93,8	×	— —	64,04 64,04	×	66,27 66,27	— 67,9	— 69,8	— —	— —
8	93,4	64,46 ×	— —	64,02 64,02	64,99 65,00	— 66,28	— 67,85	— 69,8	— 72,2	— —
9	84,7	×	— —	58,16 58,16	59,23 59,23	60,56 60,60	— 62,3	— 64,4	— 67,1	— 70,4
10	78,6	×	— —	54,2 54,2	— 55,45	— 56,86	— 58,77	— 61,1	— 64,2	— —
11	69,4	47,86 47,86	— —	×	49,33 ×	50,95 51,03	52,93 53,08	— 55,7	— 58,1	— —
12	60,5	41,67 41,67	×	42,11 42,11	43,48 43,48	45,29 45,40	— 47,9	— 51,0	— —	— —
13	56,0	38,60 38,60	— 38,15	39,15 —	40,61 40,67	42,50 42,70	— 45,4	— 48,4	— —	— —
14	48,5	33,45 33,45	— 33,13	34,20 34,20	35,82 35,82	37,94 38,3	— 41,4	— —	— —	— —
15	39,9	27,51 27,51	×	28,78 28,78	30,68 —	33,15 ~33,5	36,2 —	— —	— —	— —
16	31,3	21,58 21,58	×	23,24 23,24	25,57 25,77	28,50 29,04	— —	— —	— —	— —
17	22,3	15,35 15,35	15,76 15,76	17,74 ~18,05	20,62 ~21,2	24,15 —	— —	— —	— —	— —
18	17,8	12,30 12,30	12,97 12,97	15,35 15,50	18,67 —	— —	— —	— —	— —	— —
19	8,92	6,16 6,16	7,67 7,67	11,21 —	15,47 —	20,03 —	— —	— —	— —	— —
20	6,00	4,14 4,14	6,26 6,26	10,37 —	14,91 —	19,67 —	— —	— —	— —	— —
21	1,89	1,30 1,30	4,76 4,76	9,32 —	~13,98 —	— —	— —	— —	— —	— —
22	7,52	5,18 5,18	6,88 6,88	10,58 10,58	14,88 —	— —	— —	— —	— —	— —
23	13,1	9,04 9,04	10,01 ~10,1	12,86 13,25	16,59 ~15,9	20,8	—	—	—	—
24	18,5	12,73	13,37 ×	15,63 15,80	18,87	22,7	—	—	—	—
25	26,9	18,55 18,55	18,82 18,82	20,50 20,8	23,06	26,3	—	—	—	—

Table 1 (Cont.)

Shots No.	d (KM)	D	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
25	36,9	24,76	×	26,17 26,23	28,19 28,5	— 31,5	— —	— —	— —	— —
27	45,7	×	31,26 31,26	32,39 32,44	34,07 34,2	36,26 36,8	— 40,0	— —	— —	— —
28	55,1	38,05 38,10	37,62 37,62	×	40,04 40,04	41,92 42,2	— 45,1	— 48,3	— —	— —
29	71,0	48,86 48,96	— —	×	50,26 50,30	— 52,0	— 54,0	— 56,5	— —	— —
30	80,6	55,52 55,52	— —	55,21 55,27	56,40 56,5	— 57,85	— 59,7	— 62,1	— 64,9	— —
31	87,7	60,50 ×	— —	60,16 60,2	— 61,2	— 62,5	— 64,2	— 66,4	— 68,7	— 72,6
32	98,1	67,63 ×	— —	— 67,24	×	— —	— 70,9	— 72,8	Erratic signals	
33	107	73,58 73,70	— —	— 73,06	×	— 75,1	— 76,5	— 78,2	— 80,2	— 82,7
34	114	78,61 78,70	— —	— 78,0		— 80,0	— 81,3	— 82,8	— 84,7	— 86,9
36	12,7	8,77 8,77	9,79 9,79	12,70 12,70	16,48 —	20,65 —	25,04 —	— —	— —	— —
37	18,6	12,85 12,85	13,45 13,45	15,70 15,90	18,90 19,6	22,63 —	26,77 —	31,0 —	— —	— —
38	27,6	19,00 19,00	×	20,89 21,05	23,35 23,65	26,47 27,25	30,01 31,75	33,85 —	— —	— —
39	36,5	25,18 25,18	— —	26,57 26,59	28,62 28,85	31,25 31,75	34,35 35,85	— —	— —	— —
40	47,7	×	32,67 32,67	33,76 33,76	35,37 35,47	37,52 37,75	40,12 40,85	— 44,5	— —	— —
41	55,0	37,89 ×	— 37,45	38,40 —	39,91 39,45	41,81 42,0	44,1 44,45	— 47,6	— —	— —
42	64,9	44,76 44,76	— —	×	46,36 46,36	47,9 48,1	— 50,3	— 52,9	— —	— —
43	67,6	46,70 46,70	— —	×	48,28 48,28	49,90 49,90	— 52,2	— —	— —	— —
45	83,5	57,6 57,6	— —	— —	58,2 ×	— 58,5	— 59,7	— 61,2	— —	— —
46	93,6	64,6 64,6	— —	— 64,2	— ×	— 66,2	— 68,6	— 69,6	— —	— —
47	94,5	65,1	—	— 64,7	— ×	— 66,7	— 68,1	— 69,9	— —	— —

Table 1 (Cont.)

Shots No.	d (KM)	D	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
48	102	70,4 70,5	— —	— 70,1	71,0 71,0	72,0 72,0	— 73,2	— 76,0	— —	— —
49	110	76,00 76,04		Undecipherable						
50	2,54	1,75 1,33	4,59 4,63	8,8 9,6	— —	— —	— —	— —	— —	— —
51	7,83	5,40 5,40	6,97 6,98	10,54 10,60	14,6 —	— —	— —	— —	— —	— —
52	12,5	8,63 8,63	9,61 9,63	12,45 12,90	16,11 —	— —	— —	— —	— —	— —
53	18,1	12,45 12,45	13,06 13,06	15,24 ~15,49	18,4 19,5	— Erratic signals	— —	— —	— —	— —
54	23,8	16,36 16,36	16,72 16,72	18,49 18,64	21,15 22,0	— Erratic signals	— —	— —	— —	— —
55	35,0	24,15	×	25,49 25,53	27,7 28,10	— 30,5	— Erratic signals	— —	— —	— —
56	44,1	×	30,23 30,23	31,26 31,36	32,88 32,96	35,0 35,4	— ~38,8	— —	— Erratic signals	— —
57	53,1	36,26	— 36,26	— 37,14	— 38,6	— 40,6	— 43,1	— —	— Erratic signals	— —
58	60,9	42,00 42,00	— 41,59	×	43,60 43,70	— 45,24	— 47,27	— —	— Erratic signals	— —
59	70,0	48,32	— 47,83	— 48,42	— 49,54	— 52,2	— —	— —	— —	— —
60	80,0	55,08 55,11	— —	— —	×	— 57,35	— ~52,0	— 60,8	— —	— —
61	88,2	60,80 60,80	— —	— —	— 64,44	61,71 61,73	— 62,86	— —	— —	— —
62	96,7	66,73 66,75	— —	— 66,32	×	— 68,30	69,78 69,4	— —	— —	— —
63	106	72,95 73,03	— —	— 72,48	×	— 74,26	— ~75,55	— 77,1	— —	— —

Note: 1. First line of each division shows the arrival time for high-frequency entries; the second line, that for middle and low frequencies; 2. Dash indicates a missing signal record; 3. Crosses indicate that the corresponding arrival cannot be separated because of the overlap of an earlier wave.

Table 2

Arrivals of refracted waves G (in sec after the shot)

Shot No.	1	2	3	4	5	6	7	8
7	16,36	22,6	23,9	27,7	29,7	—	—	—
8	14,71	28,2	30,0	33,6	—	—	—	—
9	34,49	—	—	—	—	—	—	—
10	14,22	20,0	24,0	24,6	25,2	26,1	43,1	—
11	18,6	23,6	—	—	—	—	—	—
12	10,79	24,0	29,2	36,3	—	—	—	—
13	10,00	14,8	16,6	20,9	21,9	28,6	—	—
14	8,66	9,7	15,0	15,9	18,9	20,2	24,6	—
15	7,75	9,2	12,5	—	—	—	—	—
16	6,37	12,9	16,4	—	—	—	—	—
17	4,59	5,4	9,9	—	—	—	—	—
18	4,32	—	—	—	—	—	—	—
19	—	—	—	—	—	—	—	—
20	—	—	—	—	—	—	—	—
21	—	—	—	—	—	—	—	—
22	—	—	—	—	—	—	—	—
23	2,51	—	—	—	—	—	—	—
24	4,59	5,2	5,9	6,5	—	—	—	—
25	5,70	7,5	9,2	10,5	12,3	—	—	—
26	7,04	11,3	12,2	13,5	15,9	19,6	—	—
27	8,42	14,8	20,6	—	—	—	—	—
28	9,66	28,5	—	—	—	—	—	—
29	11,82	18,5	19,0	19,6	—	—	—	—
30	14,14	20,1	26,8	28,7	33,0	39,3	—	—
31	15,43	20,8	25,0	27,0	28,4	34,8	37,8	—
32	16,48	21,8	23,0	24,6	28,0	29,0	—	—
33	—	—	—	—	—	—	—	—
34	—	—	—	—	—	—	—	—
36	3,69	—	—	—	—	—	—	—
37	4,65	6,5	—	—	—	—	—	—
38	5,86	12,5	—	—	—	—	—	—
39	7,66	9,9	12,0	13,6	14,5	16,0	17,1	18,3
40	9,00	13,7	14,2	15,6	16,1	22,7	—	—
41	9,60	11,9	15,6	16,7	21,5	26,2	—	—
42	10,00	17,5	23,0	29,5	31,2	33,3	—	—
43	11,10	12,2	16,1	18,4	23,1	24,4	25,4	32,1
45	12,48	19,8	24,5	26,4	29,0	32,5	36,0	39,2
46	15,20	16,8	20,2	22,9	23,1	23,4	25,6	27,7
47	15,00	28,7	33,1	42,6	56,1	—	—	—
48	15,28	17,7	21,7	22,8	35,0	47,6	51,6	62,8
49	16,44	19,5	24,6	28,0	30,9	45,7	48,4	55,4
50	—	—	—	—	—	—	—	—
51	—	—	—	—	—	—	—	—
52	3,27	—	—	—	—	—	—	—
53	4,14	5,5	—	—	—	—	—	—
54	5,07	—	—	—	—	—	—	—
55	6,77	7,6	8,2	11,4	12,3	13,1	14,2	14,9
56	7,80	8,9	10,0	12,6	13,3	14,6	15,6	16,4
57	8,78	10,0	11,2	13,9	14,6	15,8	20,1	27,3
58	9,87	11,1	13,1	15,7	16,5	17,8	20,6	21,3
59	14,1	29,2	36,3	—	—	—	—	—
60	—	—	—	—	—	—	—	—
61	—	—	—	—	—	—	—	—
62	13,5	—	—	—	—	—	—	—
63	15,4	—	—	—	—	—	—	—

Note: 1. Calculation precision for first arrivals, 0.02 sec; the others, not less than 0.1 sec; 2. The propagation time for refracted waves does not include that in water.

ected with the presence of faults oriented along the trend of the continental slope.

3. UPPERMOST SEDIMENTS

At depths of water in the order of several kilometers, the refraction method, as a rule, cannot produce reliable data on the uppermost deposits, because, at short distances, the surface-refracted wave arrives after the direct water wave; at longer distances, it is camouflaged by waves refracted at the boundaries of deeper layers. Basic information on the properties of the uppermost bottom deposits, as set forth in this paper, were obtained from the data on the propagation of reflected waves.

A correlation of various frequency components of the reflected waves (Table 1) shows that, for waves with frequencies as much as tens of cycles, the lagging time increases with the reflection multiplicity factor, and as the distance to the shot point decreases, i.e., with the steepening of the angle of incidence.

This phenomenon is in accordance with the assumption that the cause of the lagging is the penetration of sound rays into the bottom deposits; it suggests a lack of a sharply defined reflecting boundary at a definite depth below the bottom surface. It appears that the return of high-frequency sound energy to the upper layers is related to refraction of the explosion waves in an upper layer characterized by increasing density.

A quantitative approximation of the penetration depth and velocity of an explosion wave in the ground may be obtained by the assumption of straight-line propagation of middle-frequency components of reflected waves.

When the experimental data are plotted on a R_n^2 (D^2) graph (Fig. 6), the depth of penetration of sound into the ground is easily determined from segment r_n^2 :

$$H = \frac{c r_n}{2n} - H \quad [3]$$

where H is depth of water, c is average vertical sound velocity in water; the average vertical velocity of sound in this layer is determined from angle α :

$$c_1 = \frac{c_0 H \sqrt{\tan \alpha - c H}}{H_1} \quad [4]$$

where c_0 is the sound velocity in the sound channel.

The computations were done for various segments of each cross section; the results are given in Table 3.

As a rule, the average vertical velocity of sound in a layer increases with depth, attaining 1.8 to 1.9 km/sec at depths of 200 to 300 m. At the bottom surface, the ground velocity of sound differs but little from that in water, near the bottom (1.5 km/sec). The greatest average velocities of sound were registered in the northern part of profile 4, where a slight uplift was

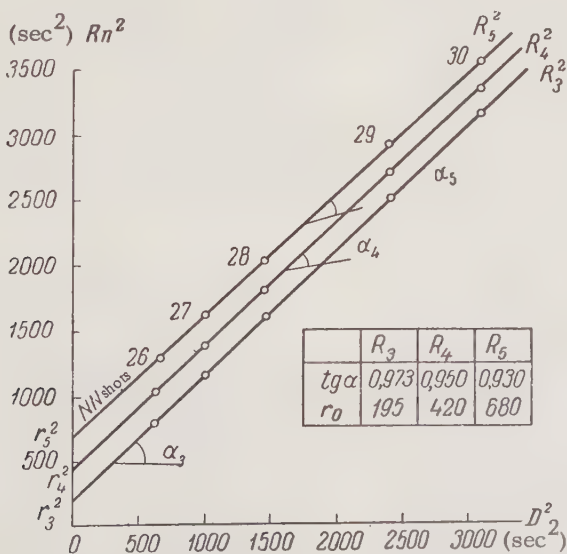


FIGURE 6. Relationship R_n^2 (D^2), by low-frequency arrivals. Profile 2.

Table 3

Cross section	Average angle of incidence ray to bottom, in °	Depth of penetration, (H_1), in m	Average velocity in bottom layer H_1 , km/sec	Critical angle, in °	Velocity of sound below layer H_1 , km/sec
2-1 eastern part	68	0	1.5	54	1.9
	62	170	1.9		
	56	270	1.9		
1-2 western part	68	0	1.5	51	2.0
	62	260	1.7		
	57	350	1.8		
4-3 southern part	62	0	1.5	50	2.1
	54	260	1.9		
	48	630	1.8		
3-4 northern part	64	490	1.5	50	2.3
	53	650	2.2		

discovered by echo sounding.

The second feature of the reflected explosion-waves propagation, which was used in the obtaining of information on the uppermost bottom layers, is the relationship between the maximum observed multiplicity factor of wave reflection, at frequencies as much as tens of cycles, and the distance, shot point to hydrophone.

The data of Table 1 show a noticeable increase in the maximum multiplicity factor, at distances to 100 km.

An analysis of the data has shown that the maximum observed multiplicity factor for reflection, approximately corresponds to the same incidence angle of sound rays to the bottom, regardless of the distance to the shot. At smaller incidence angles, the reflected signals are practically not observed throughout the length of the cross section. It is well known from the theory of propagation that, when the angle of incidence of a sound ray to the boundary between two media is less than the so-called critical angle, a sharp lowering of the reflection coefficient takes place. The magnitude of the critical angle is determined by the ratio of sound velocities on either side of the boundary. S. Katz and M. Ewing [16] have identified the minimum observed incidence angle with

the critical angle, which enabled them to determine the sound velocity in the layer below the reflecting boundary.

This method made it possible to determine the sound velocity c_1' characterizing the deepest penetration of the upper sediments by reflected explosion waves. The results of calculations are given in the two right-hand columns of Table 3.

An absence of a sharp distinction in the values of c_1 and c_1' is another proof of the absence in the upper intervals, of a clean-cut boundary characterized by an abrupt change in the velocity of sound.

4. DEEP LAYERS OF THE EARTH'S CRUST

The data on the deep layers of the earth's crust were obtained from an analysis of the graphs for refracted waves propagating along layer boundaries. The main procedure was the preparation and study of time-distance plots for refracted waves.

Fig. 7 gives a time-distance plot for refracted waves, as registered along profile 4; similar plots were constructed for all profiles. The inclined dashed line corre-

sponds to the arrival of the water wave. The almost total lack of refracted waves near the end of the profile is not typical; it was connected with a noticeable worsening of the weather.

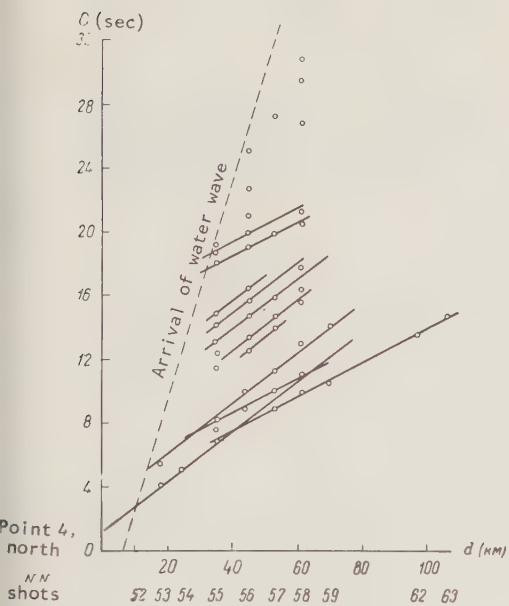


FIGURE 7. Arrivals of refracted waves. Profile 4.

By using the first, and partially the second, arrivals of refracted waves in all profiles, it was possible to distinguish two layers by substantially different velocities. In correlating the arrivals, not only the time but also their shape was taken into consideration. The main frequency of a wave refracted at the boundary of the lower layer was between 4 and 5 cycles for all profiles. The frequency of signals refracted at the boundary of the upper layer amounted to 5.5-6.5 cycles. This frequency difference is in qualitative accordance with the theory of C. Officer [17].

A study of the plots constructed for all four profiles shows that the upper of the two layers lies below the bottom surface, which suggests the presence of still another layer whose refracted waves were not observed among the arrivals; these plots arrived after the water wave, because the water depth was great (3.5 km) and the sound velocity in the uppermost bottom layers, low (about 2 km/sec). Moreover, the absence of a sharp velocity break at that boundary could have perceptibly weakened and obscured the refracted wave signal. At nearly every shot, alongside the first arrivals of refracted waves, a great number of later arrivals were registered.

The complex of these arrivals formed groups lagging for a definite period of time behind the first arrivals. Apparently, this was the result of refracted arrivals, reflected once or twice by the bottom and the water surface. The presence of several parallel lines in each group might be connected with a difference in the dip of layer boundaries.

The reverse time-distance plots for refracted waves served as material for the computation of the depth to the bottom layers, and of the velocity of sound in the boundaries between them. The computations were carried out by the conventional method developed by Ewing, Woollard, and Vine, [11] for inclined beds.

Figs. 8 and 9 show two reverse time-distance plots, for both cross sections. The value of apparent velocities along the boundaries is given directly in the draftings which also show segments T, cut on G axes by the apparent-velocity lines. It was assumed in calculations that the boundary speed of sound in the uppermost sedimentary interval was equal to 2.0 km/sec, i.e., as determined by the analysis of reflected waves. A 10 percent error in the determination of this value would lead to 1 percent error in the velocity determination for other layers; and to 10 percent of the upper layer thickness, in the depth determination.

The calculations have shown that the upper-layer boundary, below the unconsolidated bottom deposits, has a very flat dip, and boundary velocities of 6.1 km/sec over cross section 1-2, and 6.4 km/sec over cross section 3-4. This velocity difference appears to be a result of combined experimental errors, and of a lack of coincidence between the true geologic conditions and those assumed in the calculations. The boundary velocities of sound in layer 3 proved to be 7.8 km/sec, over cross section 1-2; and 8.3 km/sec, over cross section 3-4.

Fig. 10 gives the cross sections of the earth's crust, as reconstructed from our analysis. On top is a layer of unconsolidated bottom deposits, about 1.5 to 1.7 km thick at points 2 and 3; and 1.0 to 1.2 km thick at points 1 and 4. A basalt layer, with the sound velocity of about 6.2 km/sec, appears to underlie the unconsolidated sediments. Its thickness varies from 6 to 7 km at points 1 and 3 to 7 to 8 km at points 2 and 4. Underneath the basalt, there lie rocks characterized by the sound velocity in the order of 8 km/sec. This allows the identification of the boundary between the second and the third layers

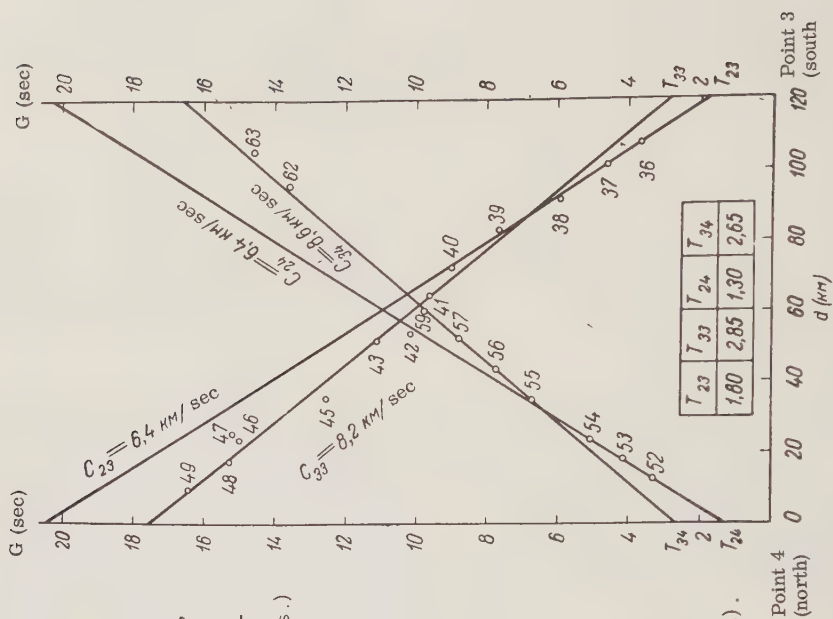


FIGURE 8. Reverse time-distance plot, cross section 1, profiles 1 and 2. (Shot number is indicated opposite experimental points.)

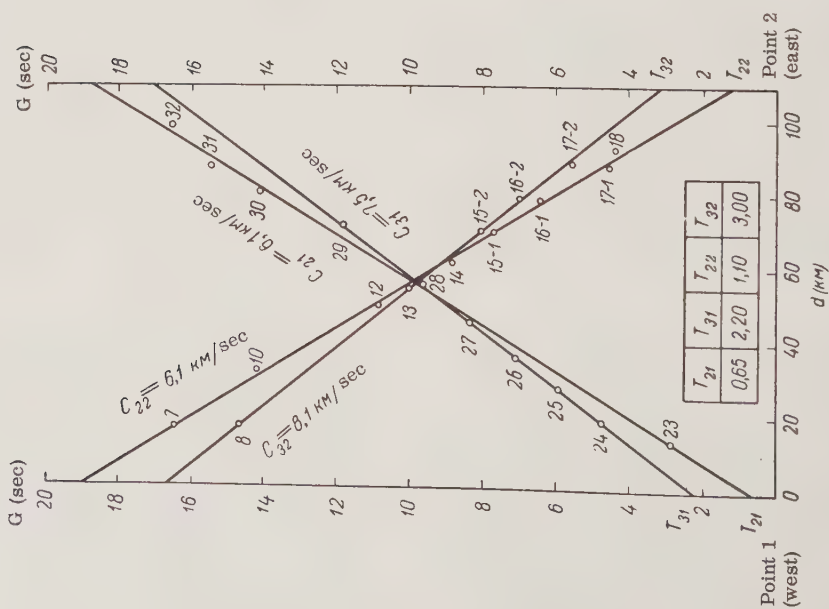


FIGURE 9. Reverse time-distance plot, cross section 2, profile 3 and 4. (Shot number is indicated opposite experimental points.)

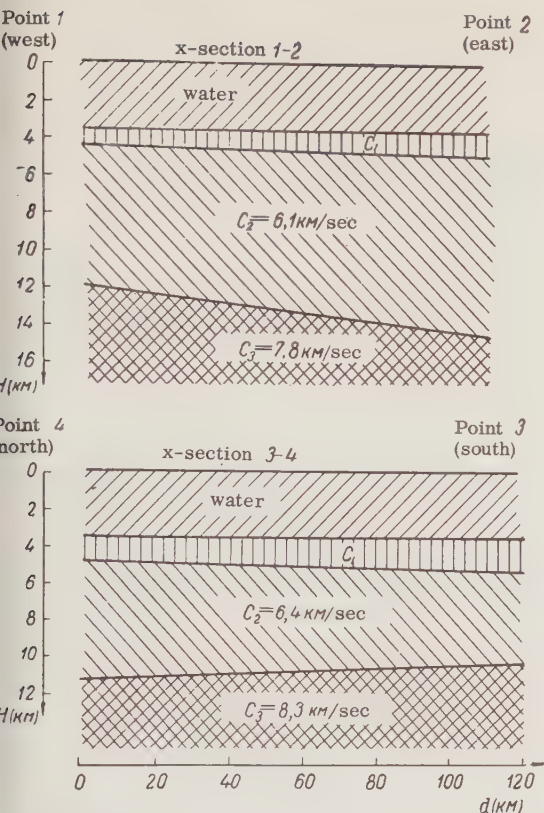


FIGURE 10. Cross section of the bottom according to seismo-acoustic data.

with the Mohorovičić discontinuity, below which there lie peridotite rocks of the sub-crustal basement. Thus, the depth of the Mohorovičić discontinuity in this area is nearly 10 to 13 km below sea level, and it dips to the southeast, at about 2° .

Such a shallow elevation of the Mohorovičić discontinuity is known to be typical for the oceanic provinces of the earth's crust, and primarily for the bulk of the Pacific. Accordingly, the Sea of Japan depression is structurally similar to the ocean bed, and probably should be regarded as its vestige. Such an opinion had been voiced by P.N. Kropotkin in his time, on the basis of his analysis of the geologic data of the adjacent land, and on geophysical data [5, 6, 7], and is now supported by M.V. Muratov [4]. The Japan-ward pitch of the Mohorovičić discontinuity, as found in the Sea of Japan depression, suggests a thickening of the crust, in the southern part of that sea, and is in accordance with the findings by the Japanese geophysicists who have studied the propagation of seismic waves in shallow earthquakes [15]. According to their data, the depth of the Mohorovičić discontinuity under the

island of Honshu and the Tshushima Straits is more than 40 km. This thickening of the crust, related to the Japanese island arc, thus separates the vestige of the oceanic crust, under the Sea of Japan, from its main body.

Deep seismic soundings of the earth's crust in the Sea of Japan furnish interesting material for a correlation of different stages of the transition zone between the Pacific bed and the continent of Asia. To be sure, the results of such deep seismic sounding are available for correlation only for the Philippine deep, and in the areas of the Eiji and Tonga islands, where deep exploration has been carried out [14, 22]. At the same time, the results of the study of the crust from the data on the propagation of surface seismic waves [20] are available for other deeps. It has been established that the crust thickness in all deeps of the Western Pacific transition zone is of the order of 6 to 12 km, i.e., typically oceanic, with the so-called L_g waves not propagating under such deeps, even as they do not propagate in truly oceanic provinces [19]. Considerable morphological differences are known to exist between different deeps of the transition zone. For instance, the Philippine and the Solomon deeps are characterized by an intensive block differentiation of their bottoms, whereas the Bering Sea depression is marked by its especially well-leveled bottom. Such morphological differences, in the presence of structural similarity, naturally call for an explanation.

First of all, the question arises as to whether these morphological differences are of tectonic origin; whether the deeps of the Bering, Okhotsk, Japanese, and East China seas are underlain by undisturbed horizontal layers. However, the data on the change in thickness of unconsolidated deposits, as obtained for the Sea of Japan, as well as the data on the stratification of the bottom deposits, as obtained by echo sounding for all four deeps, all suggest that these unconsolidated deposits fill primary relief depressions. The thickness of these sediments has been shown to be subject to radical changes suggesting a leveling of the complex basement relief by differential sedimentation. A correlation of all data on the relief of different deeps of the transition zone with those for the oceanic deeps reveals a tendency for a tectonic differentiation of the basement surface under the transition zone deeps, leading to the formation of block relief, incomparably more complex than that of the oceanic deeps. Consequently, the leveled bottom relief of some of the transition-zone deeps is more correctly associated, not with their tectonic conditions, but with the results of sedimentation, which have led

to the filling of the primary relief depressions.

Thus, two processes can be shown as having been active in the topographic development of the transition-zone deeps. The tectonic differentiation of the bottom brought about topographic features more complicated than those of the oceanic deeps, whereas a parallel accumulation of sediments, in filling up the primary relief depressions, was the leveling agent. The rise of island arcs, separating the transition-zone deeps from the body of the ocean, accelerated the tempi of the accumulative leveling-off of the primary relief. An important part in this process was played by the redistribution of the bottom sediments, effected by density currents and perennial suspension currents, responsible for the sharply differential sedimentation at the sea bottom and for a rapid filling of its depressions. In this process, the transition-zone deeps, separated from the ocean by the sills of the island arcs, act as giant suspension basins retaining the bulk of the sediments which come from the land.

In our opinion, the morphological differences of the individual deeps should be regarded as an aspect of the development stages of the transition zone. For instance, the complex block structure of the Philippine, Solomon, and Fiji deeps corresponds to a comparatively early stage of the transition zone development, whereas the East China, Japanese, Okhotsk, and Bering Sea deeps belong to later stages. The East China Sea deep, the smallest of the deeps, with a level bottom, belongs to the second group and is associated with one of the most ancient links of the transition chain, where the transformation of the oceanic crust into the continental has advanced particularly far.

SUMMARY

1. Three layers with different velocities of sound propagation have been found under the flat bottom of the western Sea of Japan depression.

2. The uppermost layer is characterized by a gradual increase in sound velocity with depth. In this layer, the velocity of sound is close to that in water, about 1.5 km/sec. At a depth of 200 to 400 m, it increases to 2.2 km/sec. It is assumed that these velocities should be identified with unconsolidated deposits in the upper part and consolidated deposits in the lower part. The thickness of the deposits increases southeastward from approximately 1.0 to 1.5 km. An increase in sound velocity in the near-surface

layer, north of the area, appears to be the result of the outcropping of basement rocks, forming a slight submarine hump.

3. The speed of sound in the layer beneath the unconsolidated sediments is about 6.2 km/sec. Its thickness increases southeastward, from approximately 6.5 to 7.5 km. This velocity is associated with basaltic rocks. The shallowness of the basalt layer is typical for oceanic provinces, whereas it lies considerably deeper under the continents. The increase in thickness of the basalt layer, to the southeast, may be associated with the roots of the Yamata submarine structure and the Japanese island arc.

4. The third and lowest layer is characterized by a velocity of sound of the order of 8.0 km/sec. Its upper boundary corresponds to the Mohorovičić discontinuity. Rocks with this velocity of sound are called the ultrabasic or peridotitic subcrustal basement.

5. In the area investigated, the Mohorovičić discontinuity lies at a depth of about 12 km below sea level; it dips southeastward at about 2° because of the thickening of the basalt layer.

6. The shallow elevation of the Mohorovičić discontinuity, and the proximity of the basalt layer to the surface, are typical for oceanic provinces. The Sea of Japan depression in this respect resembles the Philippine and other deeps of the West Pacific transition zone. These deeps can probably be regarded as representative of a distinct genetic series, the structures reflecting definite developmental stages of the continental slope transition zone.

The complex primary tectonic relief of the Sea of Japan bottom has been leveled as a result of sediment accumulation.

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ORE CONTACT METAMORPHISM OF RUDNYI ALTAI POLYMETALLIC DEPOSITS

by

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This paper discusses ore-body aureoles formed at various temperatures under changing tectonic conditions. The aureoles exhibit metasomatic zonation.

The authors distinguish between two metasomatic processes. One is developed without a substantial influx of components (with the exception of hydroxyl). The other is peculiar to the central part of the metasomatic zone and is essentially determined by the chemistry of the solutions.

* * * * *

1. HISTORY OF THE INVESTIGATION

Contact metamorphism of post-magmatic ore deposits is of considerable theoretical interest and of great practical significance. S.S. Smirnov [6] pointed out the importance of contact metamorphism in understanding the chemistry of ore-forming processes. The significance of such altered rocks as guides to ore deposits is well known. This is of a particular importance in the Rudny Altai because current exploration there has been directed chiefly to "hidden" deposits, the only guides for which are the contact aureoles.

The study of ore contact metamorphism in the Rudny Altai was initiated comparatively recently. One of the pioneers was N.N. Kurek, who described the Leninogorsk metamorphic deposits and compiled the first manual on ore contact metamorphism in the Altai polymetallic ore deposits. Since 1949 many others have studied these processes in individual Altai ore deposits. These include A.K. Kayupov and M.G. Khisamutdinov who worked on the Zyryanovsk ore deposit; G.N. Shcherba, on the Leninogorsk; P.N. Kobzar' and M.S. Bezsmertnaya, on the Berezovsk; L.K. Pozharitskaya, on the Nikolayevsk, Rulikhinsk, Shemonaikhinsk, and Zolotorsk deposits; P.F. Ivankin on the Zolotushinsk; T. Ya. Goncharova, on the Lazursk, Sugatovsk, Malevsk, and Paryginsk deposits; M.A. Petrova, on the Zmeinogorsk group; and a number of others.

In addition to these works describing, in detail, the ore contact metamorphism in individual deposits, several publications have appeared in recent years dealing with the general problem of the similarities in the Altai polymetallic contact-metamorphic

deposits, as a whole and within individual areas. Among these is a paper by M.V. Tashchinina, containing a valuable description of the mineral components of the metamorphosed rocks. The paper by L.K. Pozharitskaya on the contact metamorphism of the Shemonaikhinsk polymetallic ore deposit is also very interesting. Modern ideas on the Altai metamorphic rocks and the processes of their formation have been described by M.S. Bezsmertnaya, in her candidate's thesis.

The formation of all polymetallic ore deposits in the Altai has been long and complex, developed under various temperatures and under complex tectonic conditions, as is graphically indicated by aureoles in the hydrothermally altered rocks.

According to the sequence of mineral paragenesis, after D.S. Korzhinskiy's data on the temperature of metasomatic processes, the end products may be divided into high, medium, and low temperature alterations. "This paper takes up the origin of epidote, muscovite, and diopside replacement by fibrous amphiboles (actinolite and tremolite) as reactions which are transitional from high- to low-temperature processes. The transition from middle- to low-temperature products is featured by the decomposition of epidote and of all amphiboles, which are replaced by a stable association of dolomite and ankerite with quartz" [2, p. 374].

2. HYPOTHERMAL DEPOSITS

The earliest hypothermal products of post-magmatic activity in the Altai polymetallic belts are skarns, which are peculiar associa-

Basic Data on the Contact-infiltrational Skarn Zones of the Near-Irtysh Ore-deposit Group

Ore site	Enclosing rocks		Description of skarn zones		Products of subsequent hydrothermal stages of skarn decomposition	Ore character
	Age	Composition	Thickness	Typomorphic minerals		
Talovsk	Eifelian stage, Upper Devonian (Losishensk series)	Hornblende diabase porphyrites		Monoclinic pyroxene (salite), orthorhombic pyroxene, spinel, garnet ¹	1. Actinolite, tremolite, biotite, chlorite, epidote, (little) 2. Talc, serpentine, sericite (traces)	1. Magnetite inclusions, locally as much as 50% of rock volume 2. Sulfide ore
Shimonai-khinsk	Near the contact of Middle (Talovsk series) and Upper Devonian (Geri-khov series)	Mixed composition tuffs, acid tuffs with limy cement, possibly lime-stones	5-20 m	Grossularite-andradite, diopside	Actinolite, epidote - inner zone	1. Economic sulfide ore
Rulikhinsk	Same	Plagioclase porphyrites, limy silt-stones, tuffs	Small lenses and bands	Grossularite-andradite-pyroxene	Epidote, chlorite, albite - outer zone	1. Hematite, magnetite, muskettovite 2. Industrial sulfide ore
Nikolayevsk	Losishensk series, Middle Devonian	Limy argillites, sandstones, lime-stones		Grossularite, diopside	1. Epidote quartz 2. Prehnite - peripheral zone	1. Hematite, magnetite, muskettovite (traces) 2. Sulfide incrustation: pyrite, chalcopyrite, sphalerite, galena, bleached ore, native bismuth, bismuthine
Berezovsk	Frasnian stage, Upper Devonian (Shegirev series)	Acid tuffs with limy cement, possibly limestones	Oval nests and concretions, not over 15 cm in diameter, in chains along faults.	Grossularite, diopside, heulandite, bergite	1. Epidote, actinolite, biotite 2. Epidote, chlorite, albite 3. Quartz, albite, carbonate, chlorite	1. Scattered incrustations of magnetite and ilmenite 2. Quartz-tourmaline veins with carbonate, albite, and scattered inclusions of pyrite, chalcopyrite, native gold and silver 3. Scattered inclusions of sulfides: pyrite, chalcopyrite, very rare sphalerite, bismuthine, pyrrhotite, galena with native gold and silver

¹Garnet is listed among skarn minerals, after I. G. Mel'nik; it is not so listed by M. G. Khisamutdinov.

tions of the Paryginsk ore-deposit minerals, and anthophyllite-biotite rocks.

The Rudnyy Altai skarns are poorly developed. In the economic polymetallic mineralized zones, they are associated with ore along the southwestern limb of the Aleysk anticlinorium at the following sites: Sugatovsk, Talovsk, Shemonaikhinsk, Rulikhinsk, Nikolayevsk, Berezovsk, Zolotushinsk, Belousovsk, and in a number of localities at the Verkhubinsk ore deposit.

According to many students the skarn formation in most polymetallic ores is related to the postmagmatic stage of an intrusive cycle.

A characteristic feature of the skarns is the evidence of their very shallow origin; in F.N. Shakhov's classification [9], they are referred to a surface facies. The ore in this area is characterized by a comparatively small skarn development, by association with faults, and by a widespread manifestation of sulfide mineralization clearly superimposed on the skarns.

In D.S. Korzhinskiy's classification, the skarns from the above-named localities belong chiefly to the contact-infiltration type; a few of them to the bimetasomatic type (Nikolayevsk, Talovsk).

A majority of the skarn zones display a definite spatial relationship with faults, in that they are found in tabular, or veinlike bodies, cutting the formations. A description of skarns is given in Table 1.

As a rule, all skarn zones are intensively altered by subsequent hydrothermal processes, usually creating more extended aureoles. Commonly formed new minerals are epidote, actinolite, chlorite, and carbonate minerals.

The skarn ores are represented by scattered inclusions of magnetite, locally associated with hematite and ilmenite, and by a superimposed sulfide stage. The Berezovsk site is also known for its quartz veins with sulfide inclusions, and by an increased content of native gold and silver.

The garnets of the skarns are mostly anomalously anisotropic.

Typical hypothermal minerals of the Paryginsk granodiorite, are garnet, spinel, magnetite, and ilmenite. T. Ya. Goncharov mentions hornblende, also. As a rule, these minerals do not form deposits but are scattered throughout the metamorphosed zone in monocrystals as much as 1.5 mm in diameter. The garnets, as a rule, are isotropic. Magnetite and ilmenite are usually associated

intergrowths, with the ilmenite invariably containing minute hematite inclusions as disintegration structures of the solid solution. Several stages of this disintegration have been established.

Locally associated with ilmenite and, obviously, the products of its decomposition are rutile and sphene.

Anthophyllite-cordierite-biotite rocks were noted by M.G. Khisamutdinov in the Talovsk metamorphic zone [7]. According to him, they have been formed by the action of magnesia-rich, high temperature solutions in the shales along the foot wall of massive copper-pyrite ores.

Similar formations of copper-pyrrhotite ores in the Vavilonsk and Karchiginsk sites have been described by several authors.

3. MESOTHERMAL DEPOSITS

Mesothermal alteration is poorly developed in sulfide zones; they are little known, therefore they are discussed here only in their most general features. In localities where they are superimposed upon hypothermal metasomatism, the relation and the sequence of both processes are clearly defined.

At the Near-Irtysh group of ore sites, as well as at the Maleyevsk site, the ore process developed according to the greenstone alteration mode, whereas the greisenization process was more important at the Paryginsk site. At the Talovsk and Zyryanovsk sites, M.G. Khisamutdinov found phlogopitization, as well.

The greenstone alteration products were studied by L.K. Pozharitskaya, V.I. Kazenova, and T. Ya. Goncharova.

In all sites listed in the skarn description, mesothermal alteration is superimposed upon the skarn zones, but in each case developed aureoles are more extensive than the skarns; in some areas, especially associated with intermediate and basic extrusives, alteration has no connection with the skarns. The alteration is present throughout the skarn zone, but the best development is associated with faults, where the skarns are perceptibly shattered and almost completely replaced by minerals of epithermal paragenesis. In the remaining localities, there has been only partial decomposition and replacement of the skarns.

The two main facies of these alterations are identified by their mineral composition:

epidote-actinolite, and epidote-chlorite. Scattered pyrite incrustations are everywhere present in both facies.

The epidote-actinolite facies, evidently of somewhat higher temperature, makes up the inner subzone of skarn contact rocks whereas the lower temperature epidote-chlorite facies, represents the middle and the outer metamorphic zone. This is the more widespread facies.

Biotite is active in the paragenesis of epidote and actinolite, at the Talovsk and Berezovsk ore sites; albite, in the epidote and chlorite paragenesis of the Berezovsk, Nikolayevsk, and Rulikhinsk sites, as is prehnite in the outermost zones of the Rulikhinsk and Nikolayevsk sites.

Microscopic study has shown that in skarn decomposition, actinolite had developed chiefly from pyroxenes, whereas epidote and prehnite are from garnets. Garnet, as a mineral, is more stable than pyroxene and commonly persists where the latter has been fully actinolitized. Thus, at the Rulikhinsk and Berezovsk sites, the pyroxene is almost fully decomposed, whereas the garnet is only partially so.

The greenstone alteration is especially well developed at the Rulikhinsk site (Fig. 1) where it has spread far beyond the skarn zones, having been developed at the expense of the porphyrites in the hanging wall of the ore body. The thickness of the Rulikhinsk porphyrites is considerable. There, the greenstone alteration is zoned into the same main facies: epidote-actinolite and epidote-chlorite. The inner epidote-actinolite zone is 30 to 50 m thick. In less altered localities, it was possible to establish that epidote had developed chiefly from plagioclases, whereas actinolite developed from pyroxenes and sometimes from chlorite.

The middle zone, 50 to 70 m thick, is characterized by the development of epidote associated with quartz, chlorite, albite, and prehnite. The epidote is very unevenly distributed, but more common in the inner zone. Epidote in association with quartz occurs as concretions, as much as 10 cm in diameter, in a weakly epidotized matrix. In the outer zone, the epidote forms minute concentrations, and a network of fine monomineral veinlets, intricately interwoven but which rapidly wedge out. In this zone, the epidote commonly has been developed at the expense of carbonates.

Chlorite is more evenly distributed throughout the zone, having been developed in close association with epidote, and replacing the main body of the rock, pyroxene

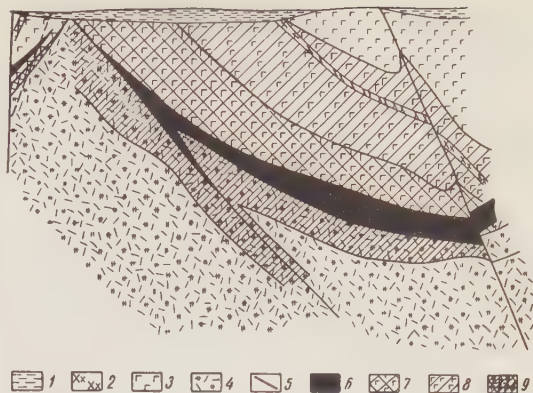


FIGURE 1. Rulikhinsk Ore Site. Diagrammatic cross section by T.V. Zorova and L.K. Pozharitskaya

1 -- Unconsolidated deposits; 2 -- plagiogranite-porphyrtes of the Zmeinogorsk complex; 3 -- diabase porphyrites, porphyrites, and tuffs of mixed and acid composition; 4 -- undifferentiated tuffs and lavas of quartz albitophyres; 5 -- tectonic breaks; 6 -- ore zone; 7 -- epidote-actinolite zone; 8 -- epidote-chlorite zone; 9 -- zone of intensive sericitization.

inclusions, and at times, plagioclase. The phenocrysts in the porphyrites also are usually replaced by chlorite. In close association with chlorite, the recrystallization of albite was progressing.

Prehnite was observed in the outermost part of the zone, only; there, it had developed at the expense of carbonates and albite of the main body of porphyrites, and in the plagioclase inclusions. Locally, prehnite has replaced chlorite in the phenocrysts.

Along its periphery, the epidote-chlorite zone is replaced by carbonate-albite-chlorite which belong to epithermal deposits and is described below.

The chemical balance in the formation of these rocks is described by L.K. Pozharitskaya (Fig. 2) who notes that it is featured by sodium leaching and an addition of water. The change in other components is negligible.

In addition to the porphyrites, the greenstone alteration also took place in tuffogenous sedimentary rocks, silico-calcareous and calcareous argillites, limestones, tuffogenous sandstones, conglomerates, and acid tuffs with an admixture of sedimentary material. However, here these alterations were less distinct and of a more sporadic character. New deposits of epidote, chlorite, and rarely actinolite, originated in the rocks, usually as small, irregular concentrations.

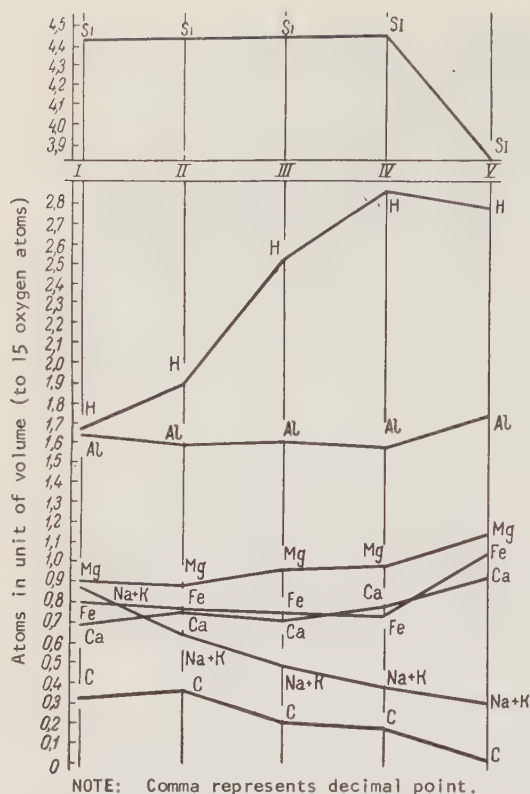


FIGURE 2. Diagram of Change in Chemical Composition of Porphyrite, in Hydrothermal Ore Contact Metamorphism, Rulikhinsk Ore Site (calculated by oxygen method).

I -- Unaltered porphyrite (average of 4 analyses); II -- Porphyrite from chlorite-carbonate alteration zone; III -- Porphyrite from Chlorite-epidote alteration zone; IV -- Porphyrite from actinolite-epidote alteration zone; V -- Porphyrite from an area of intensive pyritization.

A detailed optical and, in some cases, chemical description of the minerals, composing the new formations of the greenstone alteration zone is given by L.K. Pozharitskaya (1956). She points out a great variation in the composition and properties of epidotes and actinolites, even within a single ore deposit.

The greisenization processes are present only in the Paryginsk ore site, but even here there are no typical greisens.

The onset of the mesothermal metasomatic stage is here related, according to V.P. Bondarev, with an active influx of small amounts of Li, Zr, Sr, in F, Cl, B, and P solutions, and with the formation of the two following mineral complexes: 1) quartz, muscovite, tourmaline, apatite, albite, epidote, cassiterite; 2) the formation of sphene and rutile

took place at the same stage.

The first complex has become very widespread. It is best developed directly in the fractured belts of granodiorites, within the aureoles attaining 400 m. The second complex is more localized in contact areas of lamprophyre dikes. The thickness of the aureoles do not exceed 120 m. It is possible that molybdenite inclusions, scattered throughout the granodiorites, as discovered by V.P. Bondarev in 1954, are related to the greisenization phenomena.

In zones of secondary fracturing localized along the contacts of granodiorites with lamprophyre dikes, the new mesothermal minerals were subject to decomposition and replacement by epithermal paragenetic associations of the following minerals: pyrite-chlorite-carbonate minerals, and pyrite-quartz-sericite.

The epithermal processes terminated with the formation of sulfides, in the usual Altai sequence, and with post-ore veins of quartz and calcite, and locally with zeolite, chlorite, prehnite, fluorite, and coarse crystalline epidote. The veins are 1 to 2 m thick.

Processes of phlogopitization were observed by M.G. Khisamutdinov at the Talovsk and Zyryanovsk ore sites. In the former, phlogopitization was developed in rocks rich in alumina (shales and acid extrusives) in the hanging wall of copper-pyrite ores, as a result of the action of ferro-magnesian and potassium metasomatism.

The formation of phlogopite at the Zyryanovsk ore site was associated, according to M.G. Khisamutdinov, with an uneven temperature rise in the solutions active in the process of potassium metasomatism which had brought about the sericitization. This process is described in the following chapter.

4. EPITHERMAL DEPOSITS

Later epithermal deposits are widespread in all polymetallic ore sites of the Altai; they form the main body of rocks altered by contact processes. The formation of these rocks took place during a later period than that of the products of high and middle temperature stages, from which it is separated by a period of tectonic movements.

With reference to the formation time of polymetallic ores, the alterations of the host rocks occurred prior to ore formation; alteration of ore occurred during, and after, deposition.

Alterations Prior to Ore Formation

In all ore sites under investigation, the main metasomatic stage of alteration of the enclosing rocks was separated from the sulfide stage proper, by a period of deformation. This has been confirmed by the following investigators: M.S. Bezsmertnaya, L.K. Pozharitskaya, M.A. Petrova, M.G. Khisamutdinov, Z.V. Sidorenko. According to the data by M.S. Bezsmertnaya and M.G. Khisamutdinov, a change in the type of deformation took place during this stage. The predominant process of schistosity formation (plastic deformations) gave place to brecciation (crushing deformations).

The most widespread processes of hydrothermal metamorphism in the Altai environment are: chloritization, sericitization, carbonatization, foliation, baritization, and talc replacement.¹

Rutile is found in all ore sites, but always in negligible amounts in the altered rocks. Sphene occurs locally. In isolated instances tourmaline, fluorite, and albite, microcline, and apatite occur. Zeolites are found at the Nikolayevsk and Paryginsk ore sites, adularia, at the Zmeinogorsk and Zyryanovsk sites, and hypogenous gypsum at the Nikolayevsk ore site. Quartzitization, until recently, was thought to be one of the typical ore contact phenomena in the Altai. Microquartzites² and related siliceous rocks are widespread throughout the many ore sites, especially of the polymetallic type. This is shown at Leninogorsk, Zmeinogorsk, Petrovsk First, Zavodinsk, and Zyryanovsk. They are known from such essentially pyritic ore deposits as Grekhovskiy, Maleyevsk, Zolotushinsk, Sugatovsk, and Talovsk.

In most cases, microquartzites are emplaced in the foot wall of sulfide ores and are, in many places, themselves ore bearing, chiefly polymetallic minerals, rich in barite.

The selective affinity of lead-zinc ores and barite for siliceous rocks, and copper-pyrite ores for the chloritic types, is especially pronounced at the Zolotushinsk ore site where both types are fairly widespread.

Subsequent to the studies by N.N. Kurek

¹The last two processes, in essence, accompanied the ore formation; therefore, they are described in the next chapter.

²Microquartzites were first identified in the Altai by N.I. Kurek. By microquartzites, or hydrothermal sericite quartzites (depending on the grain size), is meant metasomatic massive rocks consisting primarily of quartz and sericite, and lacking any traces of the original structure [3].

and D.M. Shilin [5], the genesis of all siliceous rocks developed near ore sites was associated with the process of ore-contact metamorphism. In recent years, under the influence of many new facts, these ideas have been revised, and some investigators (P.F. Ivankin, M.A. Petrova, G.N. Shcherba, Z.V. Sidorenko, T.V. Kirova, and L.N. Bel'kova) have voiced the opinion that certainly not all essentially siliceous rocks, thought to be hydrothermal quartzites and microquartzites, have been formed as a result of silica enrichment from ore-bearing solutions. Many varieties of quartz rocks possess properties which give weight to the assumption of their primarily sedimentary origin, in spite of siliceous deposits being common in areas of active volcanism. At a number of ore sites (Zmeinogorsk, Bere-zovsk, Zolotushinsk), siliceous deposits in the economic mineralized zones carry micro-organic remains (radiolaria, sponge spicules).

Studies by L.N. Bel'kova (1954) have established that some siliceous rocks, namely those developed in the vicinity of the Zavodinsk mines, represent secondary quartzites gravitating toward the centers of ancient volcanic eruptions and genetically related with them.

Thus, the coincidence of silica-rich and sulfide ores at many Altai localities apparently has no genetic connection but is explained by the physico-chemical properties of these rocks which make them favorable to the penetration and circulation of the solutions. Brittle siliceous rocks are very favorable to the formation and preservation of fissures. This conclusion is in agreement with the fact that ore bodies are chiefly associated with the hanging wall of micro-quartzites.

Hydrothermal solutions, poor in SiO₂, could have dissolved and redeposited considerable amounts of primary silica; secondary hydrothermal quartzites, and in places veins and veinlets, originated by this process. The considerable amount of silica leaching and redeposition in the ore-making process at Zyryanovsk was pointed out by V.P. Prosn'yakov; at Nikolayevsk and Zolotushinsk, by L.K. Pozharitskaya; at Bere-zovsk, by M.S. Bezsmertnaya.

A lack of clean-cut distinction between siliceous rocks of different origin requires the designation of all related formations with a single name. The term "microquartzite," has a long-standing priority in the Altai, and is the most convenient, although not always genetically, precise.

Chloritization is a very common process of ore contact metamorphism in the Altai

polymetallic ore deposits, two types are differentiated: chlorite formation in the outer zones of the metasomatic aureoles proceeded at the expense of the original rocks, apparently without any additional components brought in by solutions during various hydrothermal stages. The other type of chloritization occurred chiefly in the economic ore zones, in connection with an intensive magnesian and ferro-magnesian metasomatism of an early stage of epithermal metamorphism. In the areas of dislocation and of especially active circulation of solutions, the deposition of monomineral chloritic rocks of vein type occurred at the expense of rocks of various composition, including those rich in silica.

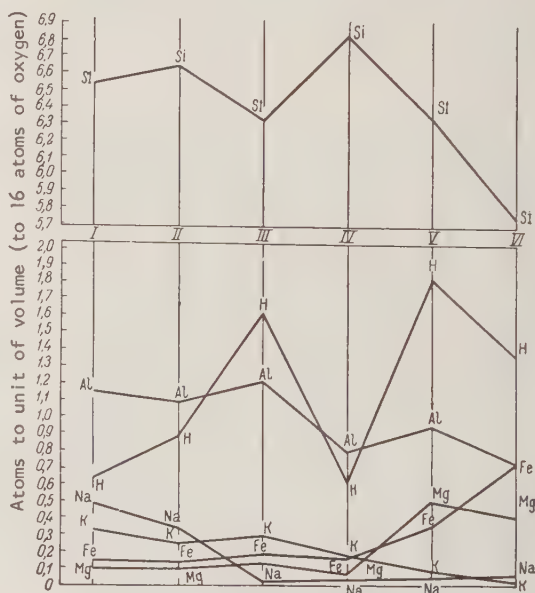
A manifestation of ferro-magnesian metasomatism at the outset of the metasomatic stage was established by M.S. Bezsmertnaya for the Berezovsk ore site; by L.K. Pozharitskaya, for the Nikolayevsk; by M.G. Khisamutdinov, for the Zyryanovsk and Talovsk [8]; by A.G. Posysoyev, for the Zolotushinsk (1953).

At the Berezovsk ore deposit, chloritization was a result of action by hydrothermal solutions of the first epithermal stage, on the enclosing rocks, as expressed in the appearance of chlorite and sericite-chlorite schists. Chlorite schists lie in elongated zones, from several centimeters to several meters in thickness, commonly in contact with essentially siliceous rocks, at whose expense they appear to have been formed. In the contact zone, siliceous rocks acquire a greenish color and contain chlorite particles aligned with the schistosity. The chloritic rocks, in their turn, commonly carry fragments of siliceous rocks, of various sizes. The areas of monomineral chloritic rocks can be traced for tens of meters, along the strike. As indicated by hydrothermal analyses, the Berezovsk chlorites belong, in N.A. Ivanova's classification, to the ferro-magnesian variety, being nearest to the rhipidolites, or else to magnesian chlorites of the prochlorite-corundum-phyllite subgroup.

At the Nikolayevsk ore site, the ferro-magnesian metasomatism is especially well traced by a regular alteration in the mineral composition of agglomeratic acid tuffs, toward the contact with the ore body. As described by L.K. Pozharitskaya, a small amount of chlorite in the cement, and a somewhat intensified pyritization (as much as 7 percent), occurs in sericitized quartz albitophyre tuffs, over 40 m from the ore body. Nearer to it, the amount of chlorite increases, the cement becoming an aggregate of quartz and chlorite, with well-defined unaltered sericitized fragments. Some 20 m away from the ore body, the chlorite-quartz aggregate begins to penetrate these fragments, with an increase in

the amount of pyrite. In contact with the ore body, the rock becomes a chlorite-quartz aggregate, well saturated with pyrite. In its optical properties, chemical composition, and thermal characteristics, this chlorite, in D.P. Serdyuchenko's classification, is prochlorite.

From chemical analyses, and from L.K. Pozharitskaya's diagram (Fig. 3) constructed from the analyses, the following alterations are inferred for the more intensively metamorphosed chloritized and pyritized tuffs of the quartz albitophyres located near the ore body: 1) iron, magnesium, and hydroxyl content is sharply increased; 2) the alkali content decreases considerably; 3) the silica and alumina content is somewhat decreased.



NOTE: Comma represents decimal point.

FIGURE 3. Diagram of change in chemical composition of quartz albitophyre tuffs in ore contact metamorphism. Nikolayevsk ore site (computed by oxygen method)

I -- Unaltered quartz-albitophyre tuff (average of 8 analyses). Leached zone; II -- partly sericitized quartz-albitophyre tuff; III -- fully sericitized quartz-albitophyre tuff. Quartzitized zone; IV -- quartzitized quartz-albitophyre tuff. Ferro-magnesian metasomatism; V -- chloritized quartz-albitophyre tuff; VI -- strongly pyritized quartz-albitophyre tuff.

Away from the ore body, the intensively pyritized and chloritized rocks give place to quartzose rocks. There is a sharp increase in silica, apparently leached from the proximate zone and redeposited farther out. Away from the ore body, there is also a sharp

drop in the hydroxyl content. Sodium is almost fully leached, but some potassium remains in quantities somewhat smaller than in the unaltered tuffs.

Still farther away from the ore body, there is a leached zone, represented by sericitized tuffs of quartz albitophyres. Here, the changes consist in leaching of sodium and addition of hydroxyls, with the other components changed but slightly.

An early stage of magnesian metasomatism prior to ore formation, was described at the Zyryanovsk site by M.G. Khisamutdinov [8]. He mentions a widespread development in the ore zone, of nearly monomineral chlorite found as metasomatic veins chiefly at the contact of microquartzites with carbonate-argillaceous schists. These metasomatic veins are quite common in the microquartzites themselves, as described by us for the Berezovsk site. Speaking of the balance between the incoming and outgoing material, M.G. Khisamutdinov [8] says: "Rocks of a composition anywhere near that of monomineral chloritic varieties, are fully lacking in this ore site. The richest in magnesia hornblende rocks, carbonate-argillaceous schists, and hornblende porphyrites, contain but 3 to 10 percent MgO and 10 to 15 percent Al_2O_3 ; i.e., their complete replacement by chlorite would require additional 10 to 15 percent MgO, 15 to 20 percent Al_2O_3 , and removal of nearly 50 percent SiO_2 , and nearly all iron."

The development of intensive chloritization in "all rocks without exception" in the fault zones of the Zolotushinsk ore site, is described by A.G. Posysoyev. His numerous sketches and factual observations illustrating this thesis, agree closely with our own observations at the Berezovsk ore site.

The Altai chloritization is not a specifically ore-forming process, but rather an aspect of regional metamorphism. In porphyrites, it also may be an aspect of autometamorphism. This causes considerable difficulty in separating the chlorite formed in the ore formation process. Establishing the outer boundary of a chloritization zone is especially difficult in basic rocks, because the manifestations of ore contact metamorphism in the outer reaches of an alteration aureole are very similar to those of auto- and regional metamorphism for these rocks. According to the data of L.K. Pozharitskaya, chlorite formed in the Rulikhinsk porphyrites, as a result of autometamorphism, differs from the mine chlorite in its lower refractive index ($n = 1.588$), positive optical sign, and higher silica content in tetrahedral grouping.

According to Yu. F. Myshkova (1956) chlorites of the Berezovsk ore zone differ from the chlorites typical of the Irtysh intensively folded zone, in their coarser grain and higher interference colors.

The ore chlorites differ greatly in their chemical composition and properties. A detailed description of the Altai chlorites is given by M.V. Tashchinina, L.K. Pozharitskaya, and T. Ya. Goncharova, for the Irtysh group of deposits.

Sericitization, like chloritization, is a typical ore contact metamorphic process in the enclosing rocks of the Altai ore sites. Two genetic types of sericitization are recognized. In the first one, the sericitization process is accomplished by the leaching of sodium. The second process is accomplished by potassium enrichment from the hydrothermal solutions. As a result of the latter, sericitolites were formed, in many places developed by replacing the chlorite rocks which, in their turn, had originated from ferro-magnesian metasomatism.

Sericitization of the first type does not exhibit any definite relationship with the ore-forming processes, being confined usually to the periphery of the alteration aureole, along the disturbed zones in acid rocks. According to many investigators, it is related to early epithermal stages of the hydrothermal process, proceeding virtually without any additional material being brought in by solutions, and solely at the expense of leaching and redistribution of the rock material.

The zonal structure of the hydrothermal alteration aureoles in acid rocks is described by L.K. Pozharitskaya, for the Nikolayevsk, Rulikhinsk, and Shemonakhinsk ore sites. She recognizes two principal zones. The inner one, in immediate contact with the ferro-magnesian metasomatic zone, is a leached zone. Its thickness is 100 m, at the Nikolayevsk site; 50 to 200 m, at the Shemonakhinsk zone; 30 to 40 m, at the Rulikhinsk zones. The leached zone rocks are represented by intensively altered tuffs and lavas of quartz albitophyres. The alteration is effected through the replacement of albite and glass, by an aggregate of sericite and fine-grained quartz.

The outer zone is that of recrystallization without any perceptible change in the mineral content. At the Rulikhinsk site, it begins at a distance of 50 m from the ore body and persists throughout the entire thickness of the explored section. The recrystallization is expressed in numerous and somewhat indistinct veinlets of coarse-grained albite, commonly hemmed by thin fringes of chlorite

and sericite. Incipient twinning occurs in the albite grains.

In the zones of progressive metasomatism, sericitization is associated with potassium enrichment from solutions. Potassium metasomatism is recognized in the Altai, by many investigators; we described it from the Berezovsk ore site, on the basis of the replacement of chlorite by sericite, in a zone of ferro-magnesian metasomatism. Along with sericite, the Berezovsk sericitolites contain carbonate and pyrite. A similar phenomenon, although on a considerably smaller scale, was described by Z.V. Sidorenko from the Zmeinogorsk ore site (1955). In certain so-called "boulder" zones of that site, according to her data, sericite replaces chlorite.

At the Zyryanovsk ore site, an intensive manifestation of potassium metasomatism, subsequent to the formation of chloritized aureoles, is noted by M.G. Khisamutdinov [8]. Accordingly, potassium metasomatism occurred during the same stage as the deposition of the main body of polymetallic ores, but somewhat before the sulfide mineralization. He states, "New minerals of this stage of metamorphism suggest a period of intensive potassium metasomatism, as well as an influx of a considerable amount of F, P, H_2S , leading to the formation of such minerals as phlogopite, muscovite, sericite, quartz, and pyrite; less commonly adularia, microcline, and apatite; still less common chalcopyrite and some sphalerite and tourmaline."

M.G. Khisamutdinov explains the presence of phlogopite in these deposits, by a differential temperature rise during the process, immediately before ore deposition; this was caused by an intrusion of aplite dikes synchronous with the youngest of the upper Paleozoic microcline granite intrusions.

The term, "sericitolite," was first introduced by N.N. Kurek, and since has acquired such a wide recognition throughout the Altai as to become an idiom with the mining geologists.

Sericitolites, as discrete rocks, were identified from the Leninogorsk mines, in 1939. According to N.N. Kurek, they are light gray rocks composed chiefly of sericite. Dolomite, pyrite, and light-colored sphalerite are present as admixtures; less commonly, other sulfides, quartz and chlorite are present. The dolomite commonly occurs in radial spherocrystals and their associations. In their external aspect, these rocks resemble serpentinites.

When dolomite or chlorite becomes a

dominant component, the rock is called dolomitolite of chloritolite, correspondingly.

Chloritoides and dolomitoides are poorly developed in the Leninogorsk mines, but are well known from the Zyryanovsk, Zolotushinsk, and Berezovsk ore sites. Evidently, they are more typical for the essentially pyritic type of ore sites, whereas the sericitolites proper are peculiar to the polymetallic bodies. We include with chloritoides, the monomineral chloritic rocks formed as a result of ferro-magnesian metasomatism.

A characteristic feature of all these rocks is a combination of bedding and vein emplacement. N.N. Kurek notes that occasionally sericitolites cut the massive sulfide ores. It does not appear that any such instances have been noticed for chloritoides and dolomitoides.

The problem of the manner in which these sericitolites originate has not yet been definitely solved. N.N. Kurek regarded them as a vein type deposit, precipitated directly from hydrothermal solutions toward the close of the ore forming process. Most investigators regard them as metasomatic rocks. The deposition mechanism for the transversal sericitolite lenses, in that case, is not unlike that for the metasomatic veins, which is in some agreement with N.N. Kurek's ideas.

Likewise, the time of occurrence of potassium metasomatism in the sequence of the hydrothermal process has not been determined. The preponderance of data from various localities, and of different investigators, suggests its proximity to ore formation. Evidently, potassium metasomatism immediately preceded the deposition of the main body of sulfides, and developed parallel with it for a while. In those ore sites where sericitization was the predominant process (Leninogorsk group), it could have been prolonged, even up to the termination of the ore making.

Of significance is the poor development of potassium metasomatism in the essentially pyritic type ores. According to the data by Pozharitskaya, potassium metasomatism is virtually lacking at the Nikolayevsk ore site, and poorly developed at the Zolotushinsk.

Carbonatization. Carbonates are typical late deposits in the ore making process throughout the Altai. Only at the Paryginsk ore site are they comparatively poorly developed. In most cases, theirs was not a separate phase of development but rather one in conjunction with some other leading process of various stages of hydrothermal activity. Three typical methods of carbon-

atization can be separated at the Altai ore sites: 1) porphyroblasts; 2) nests of irregular form, scattered throughout pre-ore quartz veins; 3) thin veinlets of a post-ore stage. Furthermore, the Berezovsk and Zolotushinsk ore sites are known to contain small metasomatic dolomite bodies emplaced in highly chloritized rocks. It is not clear, as yet, whether these bodies are independent metasomatic deposits of hydrothermally metamorphosed limestone lenses.

Carbonates of the ore process are highly diversified in their composition. The following varieties have been recognized by M.V. Tashchinina: calcite, mangano-calcite, dolomite, ankerite, siderite, and magnesite. From the optical constants, as determined by immersion, mesitite is also recognized. The most common are dolomite, ankerite, and calcite, whereas the other varieties are rare. All of the varieties, with the exception of calcite and mangano-calcite, occur in porphyroblasts. Calcite is most typical for post-ore veins and for deposits of a late polymetallic phase.

Listvenitization in the Altai is herewith recognized for the first time. We believe it possible to include in this process the quartz-chlorite-dolomite and albite-chlorite-dolomite metasomatic rocks of the Rulikhinsk and Nikolayevsk ore sites, which developed from dolomites in the outer aureole of altered rocks. As is well known, D.S. Korzhinskiy [2] thinks it advisable to broaden the term, "listvenitization," to include "all processes of ultra-basic carbonization, occurring under the action of solutions which bring about berezization of acid rocks." According to our data, the essentially sericitic rocks of the Altai are very similar to berezites, both in their origin and composition, although possessing certain specific properties. The quartz- and albite-chlorite-dolomite rocks, as described below, are developed from porphyrites, by the action of the same solutions resulting in the sericitization of acid lavas. Thus, in this case, they fit Korzhinskiy's definition of "listvenitization."

The Altai listvenites consist chiefly of dolomite and chlorite, with some admixture of either quartz or albite. It is the presence of one or the other that determines the mineral phase of listvenites, namely the quartz-chlorite-dolomite or albite-chlorite-dolomite.

The chlorite of listvenites, in its chemical composition, optical properties, and thermal characteristics, corresponds to ferro-magnesian prochlorite. The dolomite is white, with the refractive index, $\alpha = 1.500-1.505$; $\gamma = 1.677-1.687$. Spectral analyses show a constant admixture of small amounts

of iron and manganese in the dolomite.

Pyritization, in one form or another, proceeded in conjunction with the several processes of metasomatism of the enclosing rocks, with liberation of iron in the decomposition of the primary rock minerals. Its magnitude, undoubtedly, was in direct proportion to the iron content of the original rocks.

Ore Contact Alterations of the Ore Stage

These alterations are considerably less widespread and less distinct when compared with metasomatism of the pre-ore stage of hydrothermal metamorphism.

Metasomatic alteration of the ore stage essentially is a recrystallization of previously formed minerals. Thus, fine-grained chlorite changes to the coarse-grained; sericite to fine muscovite, etc.

However, some of the alterations cause a change in composition and a deposition of new mineral varieties. For example, the formation of the main body of talc is evidently connected with this stage. Talc originates at the edges of carbonate veins, and is developed where the veins cut chlorite or dolomite formations. Among the vein minerals originating during this stage (although not products of metasomatic reactions but rather the results of precipitation) are barite, fluorite, tourmaline, apatite and other minerals.

Ore Contact Alteration of the Post-Ore Stage

The alterations of this stage are somewhat similar to the previous stage. They are likewise represented by a series of quartz-carbonate veins, commonly carrying sericite, chlorite, albite, and some barite and gypsum. The vein quartz is fine grained, less commonly chalcedonic. The carbonates are chiefly represented by calcite. Characteristically, these veins cut across the schistosity, and at times across the ore body itself. The aureoles of vein distribution are quite diversified. At the Nikolayevsk ore site, the contact metamorphic rocks of this stage made up a zone a few hundred meters wide. At the Rulikhinsk ore site, the formations stretch from the ore body toward the hanging wall, a distance of 30 m, and toward the foot wall, a distance of 20 m.

5. SUMMARY

In the process of hydrothermal alteration of the Altai polymetallic ores, a very complex picture of the redistribution of late-formed hydrothermal minerals usually occurs; the character of the alterations, as it appears from the foregoing description, depends on an irregular expression and combination of many factors.

The temperature of the metasomatic processes varied in different ore sites. In some localities, metasomatic processes started with the deposition of hypothermal mineral associations (skarns), subsequently changing to the mesothermal stage (epidote-actinolite associations), but the best developed are the epithermal deposits (chloritolites, sericitolites, and listvenites). However, in most polymetallic ore sites of the Altai, the high- and middle-temperature processes were either not active or only slightly so, with the metasomatic phenomena beginning directly with the low-temperature stage.

Apart from the temperature, the mineral composition of the metasomatic deposits depended on the composition of the source rocks and of the hydrothermal solutions. Especially important was the source rock composition for the later deposition in the peripheral areas of metasomatic zones. Thus, the chloritization and listvenitization processes took place in basic and intermedi-

ate rocks. Sericitization was important in acid volcanic rocks.

As to the central parts of metasomatic zones, the composition of many late-formed minerals was determined chiefly by the content of hydrothermal solutions. This is confirmed by the fact that chloritolites and sericitolites of many sites have been developed on most diversified volcanic or sedimentary rocks.

Thus, two types of metasomatism can be distinguished. In the first, there is no substantial influx of components (save hydroxyl). This type of metasomatic rocks is more or less the result of leaching. The second type is associated with the intensive influx of components from hydrothermal solutions. The initial and middle stages of the metasomatic process were marked by the intensive influx of magnesia and iron, which subsequently gave place chiefly to potassium enrichment. Both types are links of a single metasomatic chain.

All this is in full accordance with the ideas of metasomatic phenomena developed by D S. Korzhinskiy [2], and is confirmed by the presence of metasomatic zonation in a number of Altai polymetallic ore deposits.

An idealized outline of the development of metasomatic zones for the Altai polymetallic ore sites is as follows (Table 2).

Table 2

Zone	In acid volcanics	In intermediate and basic volcanics	In sedimentary, argillaceous, and carbonate rocks	↑ Direction of movement for hydrothermal solutions
Of recrystallization	Albite-sericite rocks with quartz	Albite-chlorite-dolomite rocks	?	
Of leaching	Quartzite-sericite rocks	Quartz-chlorite-dolomite rocks	?	
Of ferro-magnesian and potassium metasomatism	Hydrothermal quartzites and zones of development of quartz veins and veinlets Chloritolites Sericitolites Ore zone			

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CERTAIN FEATURES OF SMALTITE-CHLOANTHITE OXIDATION PROCESS

by

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The authors believe that a zonal structure is usual for smaltite-chloanthite. The individual zones, judging by their contacts, are differentiated by their chemical composition, and by their nickel and cobalt content, with cobalt arsenide - skutterdite, as a consistent component. Its accumulation in partially oxidized specimens may be the cause of the enrichment by cobalt of their arsenide portion.

* * * * *

It is well known [15] that a characteristic feature of smaltite-chloanthite is its zonal structure, easily demonstrable by treating polished sections with various solvents.

This property of smaltite-chloanthite is usually caused by the different composition of its component zones. Thus, in contact imprints with rubeanic acid, as obtained for coarse crystalline aggregates and individual crystals, some of the zones are intensely blue, whereas the color of the others is paler, and not pure blue but reddish blue. Such a distribution of color may only be the result of zones being represented by a mineral rich in nickel, whereas others are represented by a cobalt-rich mineral.

It is of interest that coarse-crystalline aggregates with fairly good facet differentiation are usually marked by a parallel alignment of their zones, in relation to each other and to the outer crystal facets (Fig. 1).

Moreover, some of the specimens display clean-cut, beaded zonal areas similar to those described by G.G. Lemmleyn [4], for some quartz crystals. Some specimens exhibit the appearance of zones at a particular moment of crystal growth, and their disappearance in later stages. Such small zones, truncating the principal zones of the crystal, are seen on Figure 1. Their appearance, and that of the beaded zonal areas, probably was the result of a change in the crystal growth conditions, bringing about a change in the speed of the development of individual facets.

Thus, in their morphological features,

the individual smaltite-chloanthite crystal zones are typical growth zones.

In the study of partially oxidized smaltite-chloanthite specimens, it has been established that the individual crystal zones do not behave in the same way: some oxidize slower than others. The zonation thus revealed is characterized by the same morphological features as revealed by the treatment and with the help of contact impressions.

Figure 2 shows a polished specimen of coarse-crystalline smaltite-chloanthite aggregate. From the surfaces, the crystals of this specimen appeared to be fully homogeneous. However, a crosscut revealed but a small amount of residual arsenide, forming, apart from the outer crust, a series of zones of various thickness, alternating with secondary minerals with smolyaninovite and erythrite predominant among them.

A similar picture was observed under the microscope, for some specimens. Figure 3 shows a specimen with residual zones of unoxidized arsenide, alternating with the sooty products of oxidation.

The zonation of smaltite-chloanthite, in oxidation, is present even when the mineral has been replaced almost fully by secondary products (Fig. 4).

It is of interest that in some cases the smaltite-chloanthite zonality is present inside the grains, only, with the outer crust of such grains almost unaffected by the oxidation products. In their optical properties, these crusts are similar to the stable

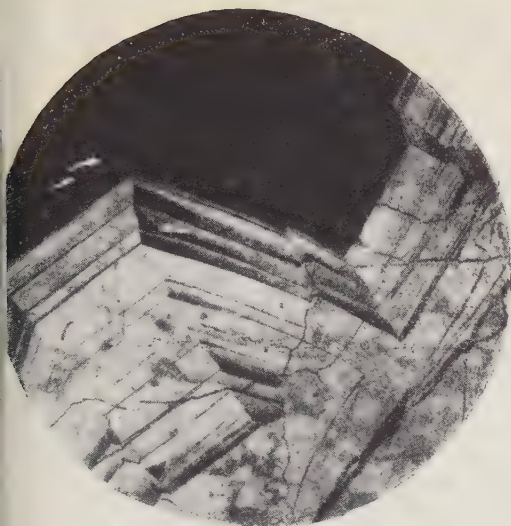


FIGURE 1. Zonation of smaltite-chloanthite, as revealed by treatment with concentrated ammonia, current 4V, 30 sec.

Black, upper part - calcite. Polished section without analyser; 54X.



FIGURE 3. Beaded structure of individual smaltite-chloanthite areas, as revealed in its zonal replacement by supergene minerals.

Polished section without analyser, 130X.

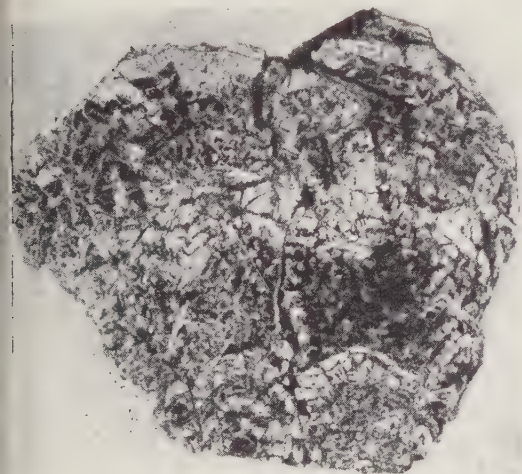


FIGURE 2. Smaltite-chloanthite zonation as a result of partial oxidation of the specimen

Light color - remaining zones of smaltite-chloanthite; gray - mixture of various supergene minerals. Natural size.

interior zones (Fig. 5).

A study of the zonation as revealed by the treatment of polished sections, and of the partially oxidized specimens, shows that the treatment and oxidation resistant zones of smaltite-chloanthite are characterized by

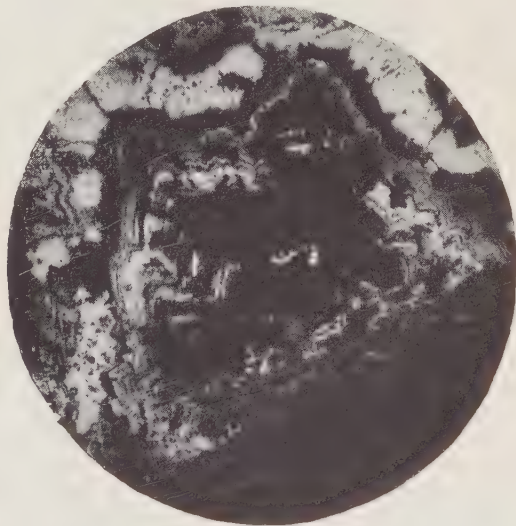


FIGURE 4. Residual zonal structure in smaltite-chloanthite, preserved in a strongly oxidized specimen.

Black - the sooty supergene material; gray - calcite. Polished section without analyser; 77X.

a higher reflecting capacity and greater relief, also greater hardness as compared with the easily oxidized and decomposed zones. These properties of the individual

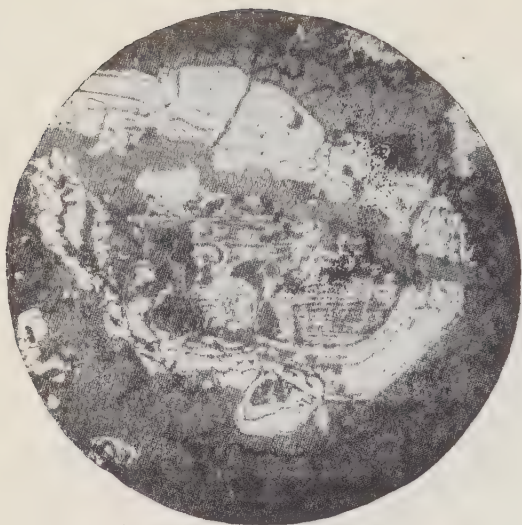


FIGURE 5. Unoxidized arsenide fringe about a zonally oxidized smaltite-chloanthite grain.

Gray - secondary minerals. Polished section, without analyser; 54X.

zones, as well as the results of contact impressions, and of a previous study of the nature of smaltite-chloanthite (10, 11, 13, 15), made it possible to assume that its cobalt component is the most stable one.

In order to clarify this assumption, a number of chemical analyses were carried out, on smaltite-chloanthite from one of the ore sites. Specimens of different genetic development were analyzed, some of them partly oxidized. In the latter case, the residual unoxidized arsenide was analyzed, carefully separated from the other products.

The specimen was broken up in Abich's mortar, then passed through a set of sieves. Only that fraction was used which contained the minimum amount of extraneous growth in the arsenide grains.

The fraction thus selected underwent triple cutting by bromoform. It was then washed with ethyl alcohol, dried out, and subjected to magnetic separation by a powerful permanent Sochnev magnet. The nonmagnetic fraction was processed cold, for 5 to 8 minutes, in 6 percent (by weight) HCl, in order to dissolve the traces of residual carbonates and the oxidation products. The residue was washed in distilled water, until its reaction to chlorine ion ceased, and dried in a thermostat at $50^{\circ}\text{C} \pm 2^{\circ}$. After drying, smaltite-chloanthite was finally picked up under a binocular lens, and chemically analyzed.

The analysis of each specimen was carried

out in two installments. Arsenic was determined by sodium hypophosphite, with subsequent titration of metallic arsenic with iodine solution [3]; sulfur was determined by the Allen-Bishof method [7, 8]; the water content, by the Penfield method [2]; the other elements, from one installment, soluble in nitric acid. Then the nitrates were changed into chlorides, out of which Sb, As, and Bi were precipitated by hydrogen sulfide [1, 8].

The iron in filtrate was separated from the other elements by precipitation in the presence of pyridine [6]. Then it was reprecipitated by ammonia [1] and its amount determined iodometrically.

Cobalt and nickel were precipitated out of filtrate as sulfides, by hydrogen sulfide in the presence of pyridine [6]. The sulfides were dissolved in nitric acid, then the nitrates were changed into chlorides. Nickel and cobalt were precipitated from an aliquot portion of the solution, by sodium anthranilate [9]. From the other portion of the solution, nickel was precipitated by dimethylglyoxime. The cobalt content was determined by the difference. The calcium determination was done for its oxalate; the magnesium - as pyrophosphate [2].

The precipitates of sulfides of Sb, Bi, and As were acted upon by ammonia polysulfide. Sulfides of As and Sb were precipitated out of filtrate, then dissolved, and Sb was separated from As by hydrogen sulfide, in a strongly acid medium. The final determination of Sb was done by the calorimetric pyridine-iodide method [8].

The bismuth precipitate residue was dissolved in nitric acid, and the amount of bismuth was finally determined calorimetrically, with thiourea [8].

The final result was taken as the average of two parallel determinations, provided the difference between them did not exceed a certain definite value. Otherwise, the analysis was rerun from new installments.

In some cases, the total analysis did not come sufficiently close to 100 percent. Apparently, this was first of all the result of the water content in the specimens having not been taken into consideration. Moreover, small amounts of secondary products may have remained in the specimens.

All of the chemically analyzed specimens were also subjected to spectral analysis, which did not disclose, in the majority of cases, any perceptible amounts of admixtures (Table 1).

The chemical-analysis results (Table 2)

Table 1
Results of Spectral Semi-Quantitative Analysis of Smaltite-Chloanthite

Specimen no.	Co	Ni	Fe	As	Sb	Bi	Cu	Zn	Ag	Si	Al	Ca	Mg	Mn
2403	> 1,0	≥ 1,0	0,1-1,0	> 10,0	0,01-0,1	0,1-0,05	0,5-0,001	0,01-0,04	0,001-0,01	present	none	0,001-0,01	traces	none
2138	> 1,0	> 1,0	0,1-1,0	> 10,0	0,1-1,0	0,1-0,1	0,05-0,5	none	0,005-0,05	present	little	0,1-1,0	0,01-0,1	0,01-0,1
2120	> 1,0	> 1,0	0,1-1,0	> 10,0	0,05-0,5	0,01-0,1	0,01-0,1	none	traces	0,01-0,1	0,05-0,5	0,005-0,05	0,005-0,05	none
2025	> 1,0	≥ 1,0	~ 1,0	> 10,0	0,1-1,0	0,05-0,5	0,05-0,5	0,01-0,1	0,001-0,01	0,05-0,5	0,1-1,0	> 1,0	0,01-0,1	0,05-0,5
2036	> 1,0	> 1,0	0,05-0,5	> 10,0	0,1-1,0	0,1-0,1	0,001-0,01	none	traces	present	little	0,1-1,0	0,01-0,1	0,05-0,5
3082	> 1,0	≥ 1,0	≥ 1,0	> 10,0	≥ 1,0	0,1-1,0	0,001-0,01	none	traces	present	present	0,001-0,01	0,001-0,01	none
3167	> 1,0	≥ 1,0	0,1-1,0	> 10,0	0,1-1,0	0,05-0,5	≥ 1,0	none	0,005-0,05	0,001-0,1	0,05-0,5	0,005-0,05	0,005-0,05	none
2253	> 1,0	≥ 1,0	≥ 1,0	> 10,0	0,05-0,5	0,01-0,1	0,05-0,5	none	0,001-0,01	0,01-0,1	0,005-0,05	0,005-0,05	0,005-0,05	0,005-0,05
2402	> 1,0	> 1,0	0,1-1,0	> 10,0	0,1-1,0	0,01-1,0	0,001-0,01	none	0,001-0,01	present	0,001-0,01	0,001-0,01	0,001-0,01	none
75	> 1,0	≥ 1,0	≥ 1,0	> 10,0	0,1-1,0	0,01-1,0	0,1-1,0	0,1-1,0	traces	0,01-0,1	0,05-0,5	0,05-0,5	0,01-0,1	0,05-0,5

Note: Comma represents decimal point.

¹Elements Sn, Mo, W, Au, Te, Sc, Be, Pt, Ta, Nb, Ti, Pb, Cd, Ga, Ge, Ti, Sr, Ba, Cr, V, P were not found. All analyses were carried out by I. V. Rozenberg, Spectral Lab., Chair of Mineralogy, Mosc. State Univ.

show above all that the analyzed specimens of smaltite-chloanthite differ greatly in their elemental content, especially for cobalt and nickel, whose amount varied fairly widely. Their iron content varied but slightly.

All specimens are characterized by a high (As + S)/Me ratio, which is near 3 for most of them. Because of that, all of them should be referred to as skutterudite; however, the latter is utterly lacking in zonation which was very distinct in all of the analyzed specimens. Because of this as well as the constant and at times fairly high nickel content, it was possible to designate all samples as smaltite-chloanthite.

The content of S, Bi, Sb, and other elements is negligible in most specimens. Only specimen 2025 has a large amount of mechanical admixture of calcite, because it has not been previously treated with HCl.

In Table 2, all specimens are listed in the ascending order of cobalt content, from top to bottom. A sharp increase in the amount of this element is well marked in the four lower specimens. It is to be noted that these specimens, in contrast with the upper ones, are arsenides separated from partially oxidized aggregates. Thus, the chemical analysis results show that an arsenide, stable in oxidation, is characterized by a higher cobalt content than that making up the less stable zones.

The same specimens were subjected to X-ray study. The results are given in Table 3 where the specimens are listed in an order reverse from that of Table 2. For correlation, the same table gives the results for standard specimens of skutterudite and smaltite, as obtained by Oftedal [12].

Table 3 shows that all specimens have similar debayegraphs, with the same indices of reflection surfaces, and like intensity lines. At the same time, all these debayegraphs are similar to the standard. This similarity is evidently related to a structural similarity between skutterudite and smaltite-chloanthite, as pointed out by Oftedal [12] and Holmes [10]. However, along with these similarities, there are certain differences in the debayegraphs of individual specimens, especially well expressed in their lattice parameters.

First of all, there is the obvious fact that all four arsenides from the partially oxidized specimens are marked by the lowest lattice parameters as compared with the unoxidized arsenides (sp. 3082, 2036, 2025, 2120, 2138, 2403). In addition the lattice parameter for these specimens depends on their cobalt content, decreasing with an

Table 2
Results of Chemical Analysis of Smaltite-Chloanthite¹

Specimen number	Weight %					Other components, in %	Total	As + S	Atomic ratios in % (Co + Ni + Fe = 100)		
	Co	Ni	Fe	As	S				Me	Co	Ni
2403	5,61	14,07	1,26	77,68	0,59	Bi—0,003; Sb—0,06; insol. res. —0,12	99,39	2,95	26,6	67,1	6,3
2138	7,58	11,59	2,19	74,72	1,53	Bi—0,15; Sb—0,25; insol. res. —0,40	98,41	2,86	35,2	54,1	10,7
2120	7,56	11,47	1,38	77,26	0,69	Bi—0,003; insol. res.—0,21	98,57	3,02	36,8	56,1	7,1
2025	7,26	10,71	1,51	67,32	1,61	CaO—5,72; Sb—0,04; H ₂ O [±] —4,77; insol. res. 0,12; CO ₂ —much (4,49) ²	96,06 (100,55) ³	2,85	37,0	54,9	8,1
2036	8,58	9,76	1,68	72,61	0,96	CaO—1,72; Sb—0,41; Bi—0,08; H ₂ O [±] —2,70; Al ₂ O ₃ —0,20; insol. res. —0,29	99,05	2,92	42,6	48,6	8,8
3082	8,80	10,66	0,98	77,87	0,86	Bi—0,012; Sb—0,24; insol. res. —0,19	99,61	3,06	42,8	52,1	5,0
3167	9,48	9,85	1,00	75,90	1,15	Bi—0,14; Sb—0,30; insol. residue —0,13	97,11	3,03	46,4	48,4	5,2
2253	10,62	9,05	1,61	75,67	1,77	Bi—0,01; Sb—0,19; insol. residue —0,41	99,33	2,93	49,6	42,5	7,9
2402	10,32	7,82	2,26	75,50	1,44	Bi—0,039; Sb—0,29; insol. residue —1,93	99,63	3,02	50,2	38,2	11,6
75	13,52	7,05	1,69	77,51	0,83	Sb—0,07	100,67	2,79	60,4	31,6	8,0

Note: Comma represents decimal point.

¹Specimens 2403, 2120, 2025, 2036, 3082, 3167, 2402, 75 were analyzed by V. A. Kudryakova; 2253, by A. A. Godovikov; 2138, by A. A. Godovikov and L. Kunasheva; 2402 is strongly oxidized (Fig. 2); 3167, 2253, 75 are partially oxidized; 2403, 2138, 2120, 2025, 2036, 3082, 3167 are nonoxidized specimens of different genetic types.

²The figure in parentheses has been computed on the assumption that all of the analyzed calcium was a calcite component.

³The figure in parentheses includes CO₂ in the mechanical admixture of calcite.

Results of X-Ray Analysis of Smaltite-Chloanthite¹

Note: Comma represents decimal point.

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Table 3, Continued
 Results of X-Ray Analysis of Smalrite-Chloanthite¹

hkl	Skutterdite Skutterud, Norway ²		Sp. 75		Sp. 2402		Sp. 2253		Sp. 3167		Sp. 3082		Smalrite fr. Rich- elsdorf ²		Sp. 2036		Sp. 2025		Sp. 2120		Sp. 2138		Sp. 2403	
	I	d/n α	I	d/n α	I	d/n α	I	d/n α	I	d/n α	I	d/n α	I	d/n α	I	d/n α	I	d/n α	I	d/n α	I	d/n α	I	d/n α
444, 730 β	5	1,181	—	—	7	1,187	7	1,187	6	1,189	5	1,191	7	1,194	8	1,190	3	1,191	7	1,192	6	1,188	4	1,192
731 β	—	—	1	1,186	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
710, 550, 543	4	1,158	3	1,160	5	1,163	5	1,163	4	1,164	4	1,167	5	1,169	4	1,165	2	1,168	5	1,169	5	1,163	3	1,169
711	—	—	1	1,154	1	1,155	4	1,155	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
640	4	1,136	3	1,137	5	1,141	4	1,141	4	1,142	4	1,143	5	1,142	—	1,142	1	1,145	5	1,145	4	1,145	4	1,146
721, 633, 552	4	1,115	4	1,116	5	1,118	4	1,118	4	1,120	4	1,121	5	1,126	—	1,120	1	1,119	5	1,121	4	1,121	4	1,126
820 β , 642 β	1	1,100	—	—	2	1,101	1	1,101	1	1,101	1	1,101	1	1,106	4	—	—	—	1	1,106	3	1,100	1	1,106
730	8	1,076	6	1,079	8	1,080	8	1,081	3	1,080	8	1,083	10	1,083	8	1,082	6	1,083	8	1,085	8	1,082	9	1,086
731	—	—	1	1,066	3	1,069	3	1,069	2	1,070	2	1,073	—	—	2	1,073	—	—	1	1,075	2	1,071	1	1,075
831 β , 750 β	3	1,056	1	1,054	5	1,054	3	1,055	2	1,055	3	1,057	4	1,065	3	1,057	1	1,058	3	1,059	3	1,056	2	1,060
732, 651	7	1,040	6	1,044	8	1,044	7	1,046	6	1,046	8	1,048	7	1,050	7	1,047	4	1,047	8	1,049	6	1,046	5	1,050
662 β	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
800	2	1,026	2	1,029	5	1,029	4	1,029	—	—	—	—	—	—	5	1,030	2	1,033	5	1,032	2	1,032	1	1,033
811, 741, 554	2	1,007	—	—	5	1,013	4	1,014	2	1,015	4	1,017	4	1,018	3	1,015	—	—	5	1,017	2	1,014	1	1,020
820, 644	5	0,9927	6	0,9978	7	0,9978	6	0,9990	6	0,9987	6	1,001	7	1,001	6	1,000	3	1,002	7	1,002	5	0,9983	4	1,004
821	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
653	5	0,9787	—	—	5	0,9844	4	0,9952	—	—	5	0,9871	5	0,9867	5	0,9862	2	0,9876	6	0,9880	—	—	—	—
822, 660	8	0,9641	—	—	5	0,9746	—	—	—	—	5	0,9746	8	0,9732	5	0,9744	—	—	8	0,9746	—	—	—	—
831, 750, 743	10	0,9522	—	—	—	—	—	—	—	—	—	—	10	0,9604	—	—	—	—	—	—	—	—	—	—
Lattice Parameter α in μ	8,189		8,207		8,236		8,244		8,242		8,265		8,24		8,254		8,260		8,271		8,252		8,294	

Note: Comma represents decimal point.

¹All specimens were photographed under nonfiltered iron radiation, under standard conditions, with an URC-70 installation, RKD camera, and computed by A. A. Godovikov. Specimen 2403 photographed in camera RKU-114. Visual estimate of line intensity. Final value for the lattice parameter was determined by graphical extrapolation of the results as calculated for individual lines up to angle $0 = 90^\circ$, with precision as much as ± 0.002 kx.

²Data from paper by V. I. Mikheev and V. N. Dubinina [5]. These specimens were photographed under copper radiation, at 30-40 kV and 10-20 mA; exposure 2-3 hours.

increase of this element in the mineral. Specimen 75, the richest in cobalt, has a parameter closest to that of skutterudite.

Thus, the X-ray data, too, suggest that, in the oxidation of smaltite-chloanthite, its most stable component turns out to be the one rich in cobalt. It is clear, therefore, that the stable component of smaltite-chloanthite, in all its properties, optical, chemical, and X-ray, is related to skutterudite. Accordingly, in the oxidation of arsenide ores that are rich in smaltite-chloanthite, an increase in relative content of cobalt in the arsenide fraction will take place, because of an increase in the relative content of skutterudite in it.

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NEW DATA ON THE TECTONICS OF NORTHERN ERGHENI

by

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In its regional aspect, the structure of southeastern European Russia, including the Ergheni, was treated in the well-known works of A.P. Karpinskiy [2], A.D. Arkhangel'skiy [1], and N.S. Shatskiy [6]. However, the actual data on the geostructure of northern Ergheni were very scant because of a thick blanket of Quaternary and upper Pliocene continental deposits.

The published works by A.D. Arkhangel'skiy [1] and Ye. V. Milanovskiy [4] point out a monoclinical structure in the northern part of that area, resulting from its location over the southeast limb of the Don-Medveditsa swell.

N.S. Shatskiy [6, 7] believes that the area includes a projection of the Dnieper-Volga downwarp developed in the Caspian syncline, whose flank is determined by the Ergheni flexure, extended meridionally.

The drilling carried out in the 'thirties in the southwestern part of the area, in connection with the Greater Donbas problem, established an uplifted zone of Carboniferous disturbances, pitching sharply to the northeast [5].

Most recent data obtained from extensive structural drilling and from earlier geophysical studies, make possible a closer approach to the complex structure of the area.

Tectonically, the north Ergheni highlands represent a heterogeneous province which includes the southern Don-Medveditsa dislocations, the west flank of the Caspian syncline, the buried northeastern extension of the Donets folding, and its companion Donets-foredeep [3].

Only two tectonic zones can be identified in the present structure of the Mesozoic and Tertiary deposits of the area: the southeastern monocline of the Don-Medveditsa dislocations, and a transition zone from the stable portion of the platform to the Caspian syncline (Fig. 1). The buried extension of the Paleozoic folded basement is reflected on a structural map drawn on the base of the Turonian, but only by a poorly defined structural nose, in the Kotel'nikovskiy area, with the Donets-foredeep not at all outlined.

The first tectonic zone, including the western part of the area, is featured by a general southeasterly dip of the beds, at 15-30'. On this monoclinical background, structural highs stand out, oriented NW - SE, also small downwarps, faults, and brachy-anticlinal uplifts trending NE. Among the latter are the Gromoslavka, Marinovskiy, and Sovetskiy uplifts (see Fig. 1). Most outstanding are the highs along a tectonic line from Surovikino, southeast to the vicinity of the village Gromoslavka. According to electric exploration data, this tectonic line coincides with a large structural high in the Paleozoic. In the Gromoslavka area, this high is transversally complicated by fracturing and by a brachyanticlinal uplift of small magnitude. The previously located Marinovskiy and Sovetskiy uplifts likewise appear to represent transversal complications upon structural highs trending southeast. The Marinovskiy uplift is normally faulted, in the northwest, the throw being about 55 m.

The Gromoslavka fault system has been identified from information from 13 boreholes cutting the faults. Underlying the Scythian and Neogene Erghenian deposits (N2) these boreholes penetrated the Maykop deposits which are as much as 100 m thick, in contact with various Paleogene and Upper Cretaceous deposits, up to and including the Santonian.

The contact of the blanket-Maykop deposits lies considerably east of the Gromoslavka dislocations, approximately along the Stalin-grad-Aksay-Kotel'nikovskiy line. Northwest of this line, the blanket deposits are removed by Pliocene and Quaternary erosion. In the area of the Gromoslavka uplift itself, all of the Paleogene is gone, and the upper Pliocene rests upon eroded Campanian. The Maykop and older Paleogene rocks are preserved only on the down-throw sides of the faults, in narrow bands, but as much as 2 km wide.

In the borehole sections, a number of Paleogene formations are missing, dips from 30° to 80° are observed on the Maykop and Paleogene beds, and numerous slickensides are present. For instance, one of the holes penetrated, below the Maykop, a Paleogene section in fault contact with Albion. The fault plane is filled with breccialike sandstone carrying numerous fragments of dark

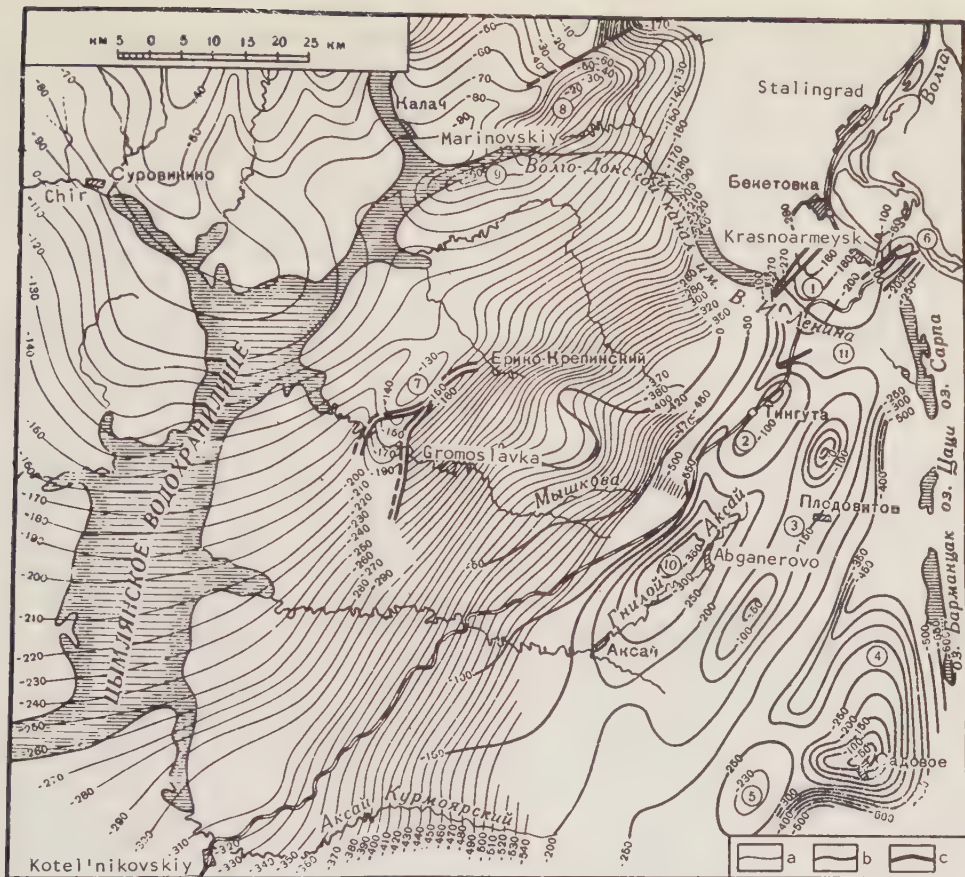


FIGURE 1. Structural map of northern Erqheni.

a -- Contours of the base of the Turonian; b -- contours on the top of a clay interval in the Tsaritsin series; c -- faults; local uplifts: 1 -- Beketovka, 2 -- Tinguta, 3 -- Sarpa, 4 -- Sadovoye, 5 -- Umantsev, 6 -- Krasnoarmeysk, 7 -- Gromoslavka, 8 -- Marinovskiy, 9 -- Sovetskii. Negative structural features: 10 -- Abganerovo depression, 11 -- Chapurnikov depression.

gray clay, porous siliceous fragments, well-rounded pebbles of quartzitic sandstone, and large chunks of Carboniferous limestones and cherts which are the usual components of the Ergheni sands. In another borehole, the Maykop is in contact with Campanian, and the Santonian with Aptian. The latter is in normal contact with the multicolored Triassic clays. Thus, this borehole has cut two faults. The throw of the lower is 165 m. In still another borehole, the Coniacian deposits contact the Albian, and the latter are in contact with the Triassic.

In some holes, about 40 to 50 m of gravel sands intercalated with clays are found between the Maykop and Upper Cretaceous deposits, apparently representing some Maykop and Ergheni formations caught in the fault zone.

The observed breaks are grabenlike, representing a system of narrow steps in a fault zone. The overall vertical displacement observed in the boreholes ranges from 100 to 300 m.

These disturbances form an arch convex to the northwest and splitting, in its central part, into two branches, with the maximum throws concentrated in its middle part, and the minima toward its ends. Geologic survey in the vicinity of the Yeriko-Krepinskiy village established step faulting of small magnitude in the northeast periphery of this dislocation, with two fault planes dipping WSW.

The field data fix the age of the faulting as follows: its initiation took place in a pre-Ergheni time, and it was terminated toward the beginning of the Scythian deposition. The

throw of the faults, toward the beginning of Ergheni time could not have been less than the thickness of the Paleogene rocks preserved on their lower sides. The upper age limit is determined by the fact that the Scythian deposits are not involved in the dislocations, whereas the Ergheni deposits are found to be strongly disturbed.

The transitional tectonic zone, taking in the east part of the area, presents, generally speaking, a downwarped province characterized by a fullness of its section and by a great thickness of Tertiary deposits; structurally, it is featured by salt anticlines trending SW - NE.

The west boundary of the area is featured by a flexure with southeasterly dips of 3° to $3^{\circ} 30'$; locally, dips as much as 30° are noted, probably associated with faults. To the south, this flexure becomes a monocline.

The positive structural features of this zone are the Tinguta, Beketovka, Sarpa, Sadovoye, and Umantsev uplifts (See Fig. 1).

The Tinguta and Beketovka uplifts belong to the edge flexure of the transition zone. The Sarpa uplift is located west of the Sarpa lakes and extends 65 to 70 km over the Ergheni water-divide plateau. Its easterly dips are 6° to 17° , and it is divided by a saddle into the South and North Domes. These three uplifts are elongated anticlines, with gentle limbs and domal terminals where the dips vary from $10'$ to $1^{\circ} 30'$, rarely attaining 4° . The anticlinal crests are complicated by local uplifts, with steeper limbs (30° - 40°) and closures from 70 to 200 m.

Of somewhat different structures are the Sadovoye and Umantsev uplifts, in the south-east corner of the area. In their configuration, they are intermediate between salt anticlines and typical salt domes. Their trend is also to the northeast, although not as well expressed as for the previously described uplifts.

Among the negative structural features of the area, the largest are the Abganerovo and Chapurnikov depressions. The first is connected with the edge flexure of the transition zone, and separates the zone from the south part of the Sarpa anticline. The Chapurnikov depression is a latitudinal downwarp, opening to the east and separates the Tinguta and Sarpa uplifts from the Beketovka and Krasnoarmeysk uplifts.

The Beketovka uplift is cut diagonally by a narrow graben, whose northwest wall is formed by the Andreyevskoye fault, first identified by E.V. Milanovskiy [4]. The presence of this fault is confirmed by a well,

drilled south of Beketovka. In this well, located on the down-throw side, dips as much as 20° were observed, with the thickness of the Quaternary and upper Pliocene deposits more than 130 m, although not exceeding 20 m on the high side. The throw is about 80 m. Near Beketovka, where the Paleogene outcrops mark the greatest uplift along the axis of the Beketovka uplift, the latter is cut by the previously identified Otradnenskiy fault.

Faults of upper Paleocene and Quaternary age, with throws of about 40 m, have been identified on the northeasterly plunge of the Tinguta uplift.

A correlation of drilling and electric data suggests that the Sarpa and Tinguta uplifts are connected in some way with the highs of the electric-log marker -- "Paleozoic surface." The electric data, although not fully reliable, probably because of rapid changes in the geoelectric section of the transition zone, still give an approximation of the depths of the rocks underlying the multicolored Permian-Triassic interval. These data suggest a lack of salt domes in the crests of the Sarpa and Tinguta uplifts. For instance, absolute elevations for an electric marker bed along the axis of the Sarpinka anticline, vary comparatively little: from minus 1550 m to minus 1800 m. In this respect, these uplifts differ substantially from the Krasnoarmeysk dome where a salt dome pierces the entire multicolored section, whereas in the Sarpa anticline the section thickness ranges from 800 to 1200 m.

A correlation of the structure of the area with the gravity data suggests that the fringe of the transitional tectonic zone is represented by a belt of easterly decrease of the gravity anomaly -- a gravity step. The latter is split locally into two isoanomaly branches, with gravity minima and maxima between them. The west branch of the gravity step is generally correlative with the edge flexure of the transition zone, whereas the east branch is superimposed upon the west limb of the Sarpa anticline (Fig. 2). The Tinguta and Beketovka uplifts are correlative with the gravity minima lying in the middle of the gravity step.

The crest sector of the Sarpa anticline is marked by a minimum gravity zone, with a local minimum in the area of Plodovitoye, its east limb is superimposed upon a belt of local gravity maxima, west of the Sarpa lakes. A vast gravity minimum corresponds to the Sadovoye and Umantsev uplifts, with the former's east limb superimposed upon a local maxima belt which hems its minimum in the east.

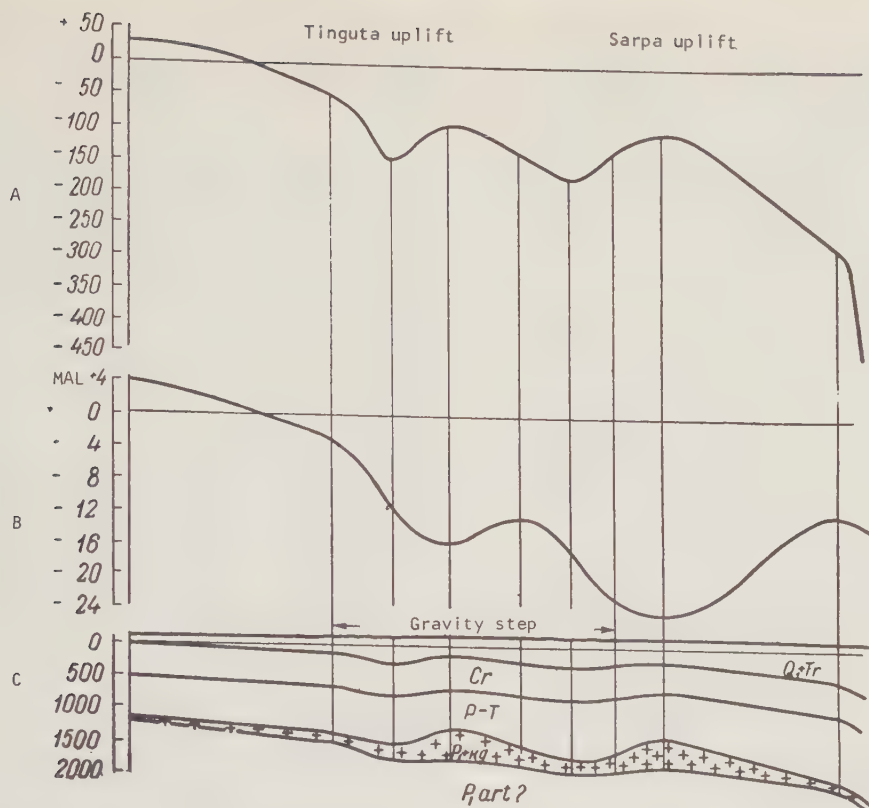


FIGURE 2. Correlation of drilling and gravity data.

A -- Relief on top of Tsaritsin clays; B -- gravimetric profile; C -- qualitative geologic interpretation of gravity data. Crosses indicate salt.

These local gravity minima are considerably displaced toward the domal terminals of the uplifts. For instance, the Plodovitoye minimum takes in the saddle separating the North and South Domes of the Sarpa anticline, whereas the Tinguta minimum is shifted toward the south domal terminal of that uplift.

All these data show that, within the transitional tectonic zone, the structural features do not fully coincide with the positive or negative gravity anomalies, but are superimposed on either. In their turn, such characteristic anomalies, as a gravity step, local minimum or maximum, are commonly induced by various anomaly-making factors and do not reflect any specific structural features, such as a fault scarp, uplift or depression. For instance, the west part of the gravity step reflects an eastward block plunge of the Paleozoic rocks, whereas its east part corresponds to the west limb of a salt anticline.

On this subject, Yu. A. Kosygin (1951)

states that there is no complete coincidence between local gravity minima and salt domes, along the west boundary of the salt dome province. As an example, he cites the Krasnoarmeysk uplift which is considerably shifted toward a gravity maximum. The reason for such a phenomenon is sought by Yu. A. Kosygin in the fact that the halogenic Permian deposits along the west edge of the salt dome province have been replaced by thick sulfate rocks. However, the Krasnoarmeysk and other uplifts, where the Permian sulfates are either lacking or else are very thin, show the fallacy of a purely lithological explanation of this phenomenon.

A correlation of drilling and gravity data throughout the transition zone area (see Fig. 2) reveals that a plunge of the limb of an uplift is accompanied by a gravity increase only up to a certain extent. The opposite is true at distances over the east limbs, sufficiently large from the crests: a greater plunge is reflected in a gravity decrease.

The observed distribution of the gravity

field may be explained by the well-known hypothesis of the formation of piercement domes, according to which the original unevenness of the salt surface, as determined by tectonic factors, results in salt flow due to differential pressure, from the surrounding downwarps and toward the crests of the uplifts. This results in salt accumulation in the crests of the tectonic uplifts, and its wedging out in the limbs. It may be supposed that the gravity anomalies' distribution throughout the transitional zone is a resultant of two main factors: salt piercement and the tectonics of the subsalt rocks. In the crestal parts of the uplifts, salt piercement is the paramount anomaly-making factor, which explains their coincidence with the gravity minima. Over the limbs of the uplifts, on the other hand, where the thickness of the hydrochemical sediments is small, a change in the gravity field is determined, generally speaking, by the depth of the heavy Paleozoic rocks; therefore, a plunge of the beds here is reflected in a gravity decrease. Such relationships have not been established for the west limbs of the uplifts. Evidently, this is explained by the fact that the west limbs of subsalt structures are flatter and of smaller amplitude, than the east limbs. The effect of the second factor determines the considerable shift of gravity anomalies in the direction of the domal terminals of the uplifts.

Thus, it may be concluded that the piercement domes of the transition zone are subordinate to the subsalt tectonic uplifts.

On the basis of our observations, the main stages in the development of the area are as follows. At the end of the Paleozoic, the southwest part of northern Ergheni was affected by folding and orogeny, which terminated the geosynclinal stage of the Greater Donbas development. The rise of the ridge was accompanied by the formation of a foredeep.

During the Triassic and Permian, the region northeast of the rising ridge was subsiding, as indicated by the great thickness of its multicolored deposits. Over the northeast limb of the downwarp, the Permian-Triassic thicknesses range from 100 to 400 m, along the east Tsimlyanskiy reservoir shore; 450 to 650 m in the Gromoslavka area; and 800 to 1200 m west of the Sarpa lakes. This limb supported highs trending NW - SE, which is confirmed by the thickness distribution in the multicolored section.

Toward the close of the Early Triassic, the area was affected by uplift and became subject to denudation. Jurassic deposits are lacking over the area; however some 200 m of Middle Jurassic deposits in the Krasnoar-

meysk locality suggest that the Jurassic sediments were eroded as a result of a terminal Jurassic uplift, as occurred over the Donets foredeep, farther west [3].

The data on the Cretaceous development of the area are more complete. Beginning with the Aptian, the area underwent intensive subsidence, although the sedimentation process was frequently interrupted. The Cretaceous transgressions, proceeding southwestward, embraced ever larger terrains. Toward the Turanian-Coniacian time, some dry land apparently persisted in the area of the submerged ridge. In the Santonian, the entire region was submerged, and the sea persisted till the close of the Cretaceous.

The isopachous maps for various stages of the Cretaceous (one of them is shown on Fig. 3) show the minimum thickness belts trending NW - SW, more or less following the present high structural trends. The Paleozoic basement high in the Kotel'nikovo area, is marked by zero and small thicknesses.

The thickness distribution for Cretaceous deposits shows that the principal structural elements of that period were gentle highs of small magnitude, trending NW - SE, and gradually plunging in the same direction.

Beginning with the Santonian, these principal structural features were complicated by small downwarps and highs, trending northeast. In Maestrichtian time, the structure was radically changed, to outline nearly all of the elements of the Cenozoic structural plan, now characterized by a north-easterly trend. Simultaneously, the edge flexure of the transitional tectonic zone was clearly defined by a sharp easterly increase in the deposit thickness.

At the end of the Cretaceous, the entire area of northern Ergheni was uplifted. The process was especially intensive in the north west part of the area, where all of the Maestrichtian and locally the Campanian deposits were eroded away. The continental interval of sedimentation comprises the close of the Maestrichtian and the Danian, as suggested by the absence of the Belemnitella americana zone and of Danian rocks.

In the Paleogene, the north Ergheni area underwent subsidence. The strongest subsidence took place in its eastern part, also in the area of the buried ridge. It was during the Paleogene that the southerly monoclinical dip toward the buried ridge, was initiated, together with the outline of the southern "terminal" of the Don-Medveditsa dislocations.

The Paleogene and Eocene witnessed the

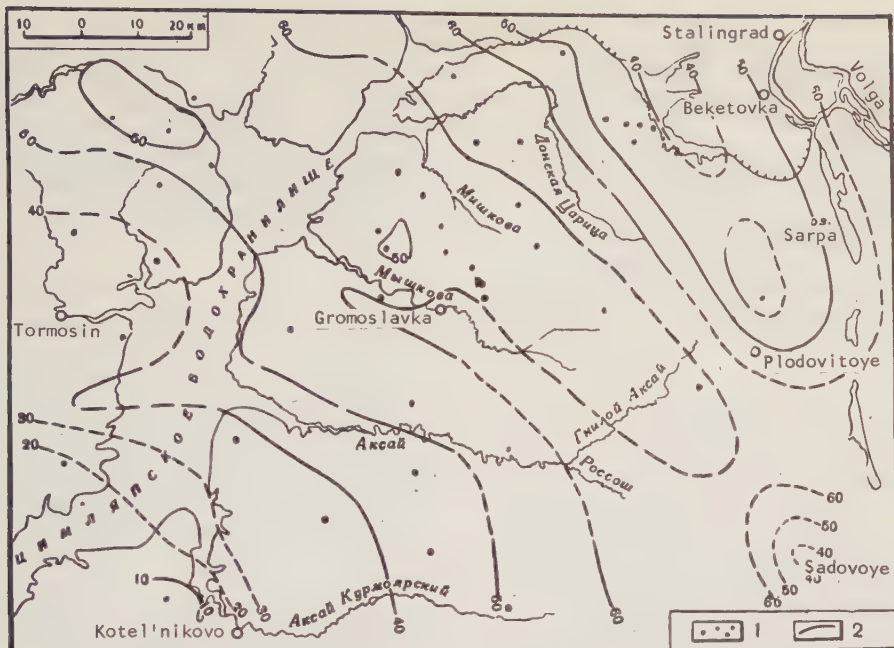


FIGURE 3. Isopachous map for the Turonian-Coniacian deposits.
1 -- boreholes; 2 -- isopach

emergence of all the details of the modern structural plan for the transitional tectonic zone (see Fig. 4). In upper Eocene time, the northwestern part of the area was uplifted, as indicated by a northwesterly wedging out of the Kiev deposits. Prior to the deposition of the *Marginulina behmi* zone of the Kiev series, the uplifts took place in the area of the Tinguta, Beketovka, and the northern part of the Sarpa anticlines. The latter is confirmed by the marls of this zone, transgressively overlying various beds of the Kiev and Mechetkin series.

Toward the close of the Eocene, the northern Ergheni area underwent another uplift, an especially strong one in the crestal parts of the transition zone, where the Kiev and, partially, the Mechetkin deposits were eroded, with nearly all of the Eocene gone, at the northern crest of the Sarpa anticline.

The onset of the Oligocene was marked by a subsidence of the entire area, and by a widespread Maykop transgression. In the Miocene, the northern Ergheni were caught in an uplift, with the sea receding eastward; after the *Oncophora* beds deposition, the area stood high. In the beginning of the Concha time, the easternmost part of the area again subsided. Marine deposits of that age are preserved over the eastern flexure of the Sarpa anticline and on the flanks of the Sadovoye dome. By the end of the Miocene, a continental regime prevailed over the

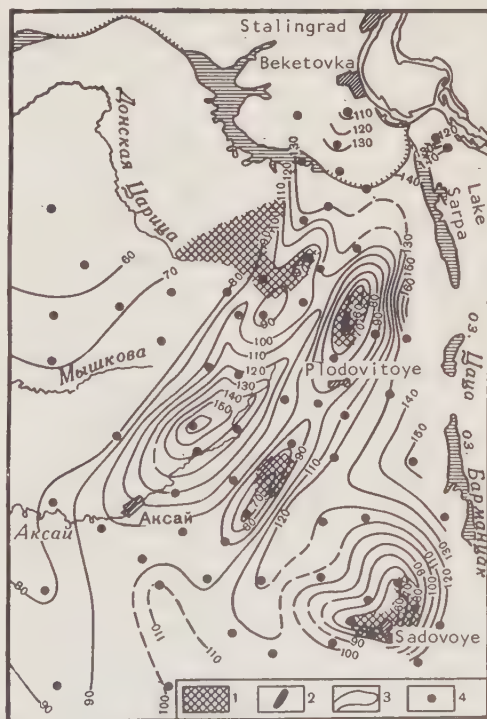


FIGURE 4. Isopachous map for the Tsaritsin and Mechetkin series.
1 -- Areas of Maykop deposits over the eroded Mechetkin surface; 2 -- areas of Maykop deposits over the Proley deposits; 3 -- isopachs; 4 -- boreholes.

entire area.

Marked subsidences took place in the Caspian syncline, during the Pleistocene [8]. These subsidences have left their traces in the subject area, as well. Thus, upper Pliocene continental deposits over the east slope of the Ergheni uplift are disturbed and show a well-defined dip toward the Caspian depression. The main results of the late Neogene tectonic movements were faults. Here belong the formation of the Gromoslavka faults, also the normal faults of the transitional tectonic zone.

SUMMARY

The Paleozoic stage of the northern Ergheni development terminated with a folded structure and a foredeep formed in the southwest part, embracing most of the area. The foredeep kept developing during the Permian-Triassic time, so that toward the end of the Early Triassic it was filled by thick multicolored beds. The northeast limb of the foredeep was complicated by southeast trending high, as early as the Permian-Triassic.

During the Mesozoic era, the main elements of the structural development were gentle uplifts whose trend was subordinated to a southeasterly extension of the Donets folding. To the northwest, these uplifts are connected with the structural steps of the Don-Medveditsa dislocations; therefore, they may be regarded as a southeasterly extension of the latter. This is a confirmation of the ideas previously voiced by A.G. Brazhnikov (1950) that the Don-Medveditsa dislocations do not die out in the interrivers area of the Chir and Don, but rather veer to the southeast into the Caspian syncline.

At the close of the Upper Cretaceous, and during the Paleogene, the structural development of the area was influenced chiefly by the marked downwarps along the west flank of the Caspian depression. They determined a radical reconstruction of the Mesozoic build-up, orienting it along a northeasterly trend. The changes were especially great in the southeastern, and more mobile, part of the area where the reconstruction was accompanied by salt piercing the crests of the uplifts. In the northwestern, and more stable, part of the area, the Mesozoic structural highs preserved their basic structural features. They were complicated only by northeast trending, small downwarps and local uplifts. These include the Gromoslavka, Sovetskiy, and Marinovski uplifts (see Fig. 1).

All of the above makes it possible to

regard the positive structural features of the transitional tectonic zone as the remains of a Mesozoic structural system whose base is the Paleozoic highs connected with the Don-Medveditsa dislocation system. Therein lies the essential difference between the piercement uplifts of the subject area and the similar structures farther north along the west flank of the Caspian depression.

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PALEOZOIC OF THE REGION WEST OF LAKE BALKHASH NEAR THE VILLAGE OF MYNARAL

by

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The desert east of Bet-Pak-Dala areas and the shores of Lake Balkhash in the vicinity of the village of Mynaral and the Karakamys granite massif, are of particular geologic interest. Here lies a thick and diversified Paleozoic section, well defined paleontologically. Its study provides the most reliable basis for the determination of the sequence and age of deposits widely developed throughout the area just west of Lake Balkhash. Of great interest are the Paleozoic intrusives which predetermined the distribution of various useful minerals, such as wolframite and molybdenite. Outlines of the geologic structure of the Mynaral area are given by D. I. Yakovlev [6], A. M. Belyayev, and A. Ye. Repkina. Especial attention was given by these investigators to Silurian deposits, represented in the vicinity of Ak-Kerme Bay by massive reef limestones.

Paleontologic collections from these limestones, as accumulated through the years, were studied by V. N. Veber [2] and O. I. Nikiforova [6] who described the trilobites and brachiopods. A brief description of individual fossil groups is found in papers by P. I. Stepanov [8], L. B. Rukhin [7], and A. Ye. Repkina. However, despite these works, the Silurian stratigraphy of Mynaral remains unclear because of a complex relationship between the volcanic and reef facies, in places difficult to unravel, because the entire section is linearly folded and faulted. In the geologic mapping, it is not clear whether the disappearance of some extrusives is the result of facies change or faulting.

Furthermore, the age of the so-called "interreef facies" of volcanic and terrigenous rocks has been obscure, up to recently. Only a large number of graptolites found in these deposits in recent years have provided a firm paleontologic basis to Silurian stratigraphy.

The field work in the Mynaral area was carried out in 1952-1955, by two collaborating groups from the Institute of Geologic

Sciences, Academy of Science, U.S.S.R. One group, under the direction of V. S. Koptev-Dvornikov, studied the Karakamys and Dzhalgyz granite massifs as well as other intrusives and extrusives of the area. In each of these years, L. V. Dmitriyev, A. V. Kozlov, E. V. Negrey, and V. A. Pavlov took part in this work; now they are preparing a monograph on the geology and petrography of the early Hercynian massifs of Bet-Pak-Dala, with V. S. Koptev-Dvornikov as editor. The data of this monograph are used by E. V. Negrey, in this paper, for the description of the intrusives of the area.

The second party, under B. M. Keller, studied the stratigraphy. This group included stratigrapher-paleontologists O. P. Kovalevskiy, (1954), V. A. Sytova (1953), M. N. Chugeyva, who subsequently studied the tabulata, tetracorals, and trilobites. A detailed geologic survey was made to clarify the structure of the area. In 1954, B. M. Keller and I. N. Krylov studied the area near Lake Balkhash. In 1955, Keller carried his studies as far as the Karakamys granite massif, to the west, including its northern fringe. This paper deals with the area of the map (Fig. 2) excluding the Ak-Kerme Peninsula. This peninsula, characterized by peculiar Ordovician and Silurian facies, (Llandoveryan reef limestones, Lower Wenlock graptolite slates) is considered elsewhere [3].

Among the undergraduates active in the Silurian study of Mynaral and in fossil collecting, were O. B. Bondarenko, N. B. Keller, I. N. Mel'nikova, A. I. Polozhukhina, S. B. Prokopenko, V. P. Tkachev, and G. P. Shishkina.

STRATIGRAPHY

Precambrian

The Archean of the Mynaral area is taken to include the gneisses and mica schists

outcropping along the northeast fringe of the Karakamys granite massif and in the horst of the northeast limb of the Mynaral anticline. The younger Precambrian formations, probably Proterozoic, are represented by greenish schistose amphibolites and light metamorphic limestones, in small outcrops along the northeast limb of the Mynaral anticline.

Well developed in the south part of the area are thick, strongly metamorphosed schists and sandstones with subordinate beds and lenses of siliceous rocks. Apparently, such deposits are common to the upper Proterozoic (Reefian) and lower Paleozoic of Kazakhstan. In the Chu-Ili Mountains, where they include lenses of pink limestones, they were usually regarded as Reefian. Similar rocks of the Kandykta ridge include lenses of dark, almost black limestones with Middle Cambrian trilobites. No such carbonate rocks have been found in the subject area; therefore a more precise dating of the green schists is still pending. It is clear, however, that they are older than Ordovician.

Similar rocks were found in the north fringe of the Karakamys granite massif, along the right bank of the Sary-Bulak River. Basic extrusives are present here, alongside the schists.

Ordovician System

The Ordovician is represented in the subject area by two types of rocks. In the south, there lies a belt of thick terrigenous deposits; to the north, along the south shore of the Ak-Kerme Bay, a quite different type of rock crops out in the middle of the Ortansk anticline. Each of the Ordovician sections is treated separately.

Southern type section. Here the Ordovician is represented by thick metamorphosed argillites and siltstones, locally reminiscent of the upper Proterozoic, schists. Their essential distinction is their darker color and a lack of siliceous beds and intercalations. The rocks may be either thick or thinbedded, locally schistose because of which graptolites and other organic remains are extremely rare. Nevertheless, a fairly well preserved graptolite of the family Diplograptidae, apparently belonging to genus *Orthograptus*, was found in the middle Kuyanda-Uzek River valley. This finding confirms the Middle or Upper Ordovician age for the enclosing rocks. Their general character suggests their correlation with the Dulankarin bed of the Chu-Ili Mountains. The Ordovician lies in sharp erosional and angular contact, upon the upper Proterozoic which is clear from a disappearance of the

siliceous Proterozoic folds underneath the transgressive dark Ordovician schists. The total thickness of the metasiltstone series in the southern section is more than several hundred meters.

North type section. The Ordovician rocks of this type crop out southwest from the Ak-Kerme Bay where they constitute the crest of a large anticlinal structure, here called the Ortansk anticline (Fig. 1).

Llanvirn. Light-gray and greenish-gray slaty sandstones and siliceous slates crop out in the middle of the anticline, carrying *Didimograptus ex gr. pacificus* Twenhofel, *Cardiograptus anna* (Hall), *Pterograptus* sp., *Climacograptus* sp. and other graptolites (identified by B.M. Keller). Overall thickness, 250 m.

Llandeilo and Caradocian. In the north limb of the Ortansk anticline, there are conformably on the Llanvirn:

1) dark-gray conglomerates and tuffaceous sandstones with rounded pebbles of granite, granodiorite, and sandstones; they form a well-defined scarp; thickness, 190 m;

2) pink and light-gray thin siliceous slates with graptolites: *Dicellograptus* sp., *Pseudoclimacograptus scharenbergi* Dapworth (ident. by B.M. Keller); thickness 320 m;

3) sandstones and metasiltstones, alternating in layers 0.2-1.0 m thick; sandstones dark gray, tough, thin; overall thickness 110-225 m.

A correlation of the south and the north section is difficult. The dark argillites of the southern section, with *Orthograptus*, are definitely younger than bed 2, and are possibly correlative with 3; however, a lack of organic remains in it makes this correlation uncertain.

Silurian System

Silurian deposits are widespread in the Mynaral area, where they form three NW-trending belts. Generally they outcrop in the crest parts of the anticlinal uplifts, and are separated by Devonian outcrops.

Llandovery stage. Paleontologically determined Llandoveryan deposits occur on the north limb of the Ortansk anticline, along the southwestern shore of Ak-Kerme Bay. Here they begin with conglomerates of pebbles, fractions of a centimeter in diameter, to blocks of several meters. The pebble material consists of gray oölitic and breccialike limestones, metamorphosed acid extrusives;

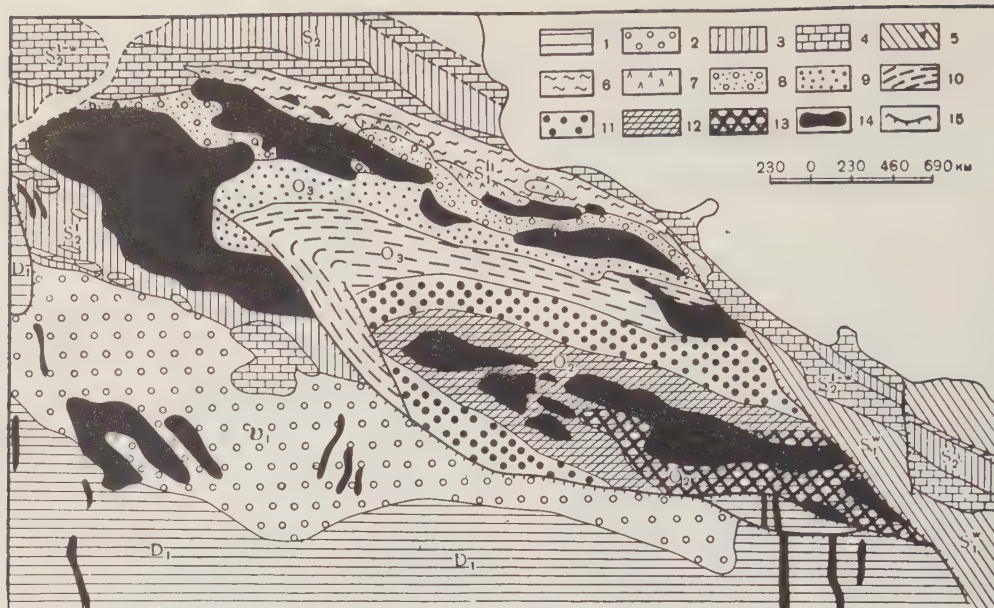


FIGURE 1. Geologic map of the Ortansk anticline (south shore of Ak-Kerme Bay)

Lower Devonian: 1 -- shales and sandstones; 2 -- conglomerates. Silurian: 3 -- Ludlow (?) red shales; 4 -- Lower Ludlow-Wenlock, Akkan limestone; 5 -- Wenlock-Tarannon, shales, sandstones, conglomerate lenses; 6 -- Llandovery, siliceous shales; 7 -- Llandovery, acid extrusives; 8 -- Llandovery, conglomerates. Ordovician: 9 -- Caradocian-Ashgillian(?), sandstones; 10 -- Caradocian, siliceous shales; 11 -- Caradocian, tuff-conglomerates; 12 -- Llandeilo, sandstones and shales; 13 -- Llandeilo, sandstones and shales; 14 -- diabases and other vein rocks; 15 -- faults.

pink, tightly cemented quartz sandstones, tuffaceous sandstones, granites, spotted siliceous rocks, and quartzites. The conglomerates carry large lenses of gray limestones. Above are fairly diversified volcanic-sedimentary rocks, with tuff and siliceous shales predominating and carrying lenses of acid extrusives, sandstones, tuffaceous sandstones, and fine-pebble conglomerates. This series terminates with pink, light gray and yellowish gray thin cherty slated with *Demirastrites aff. decipiens* Tornquist (ident. by A.M. Obut), suggesting a Llandoveryan age. The total thickness of the Llandoveryan stage, in this section, is 225 m.

In addition to these formations, whose Llandoveryan age is undoubted, here may belong the so-called Mynaral conglomerates which overlie a vast area west of Mynaral. These conglomerates are very poorly cemented, and contain pebbles and boulders of gneisses, mica schists, sandstones, and quartzites. They form a gentle anticlinal structure on whose north wing they are overlain by light-colored sandstones and meta-siltstones, barren of organic remains; on its south wing they are covered by the Wenlock and lower Ludlow limestones of the Akkan series. If the contact between the

Akkan limestones and Mynaral conglomerates is stratigraphic and not an overthrust, these conglomerates are best correlated with those of the basal Llandovery stage, as in the Ak-Kerme Bay section.

Tarannon beds (Llandovery-Wenlock). Beginning with the Taranonnan age, the Mynaral area witnessed a complex of facies, rapidly changing over short distances. Three types of deposits are recognized:

1. Limy-marl type of the Ak-Kerme Peninsula, as described by B.M. Keller.

2. Silicified slaty argillites and metasiltstones with subordinate tuffaceous sandstones and conglomerates. They are peculiar to the southeast terminal of the Ortansk anticline and to the Karaagach anticline, farther to the south.

3. Volcanic Taranonnan rocks, widespread over the monoclinical block of the south wing of the Karakamys syncline.

Several sections well illustrate the properties of the Silurian volcanics. One of them is located on the road from Mynaral to the Mayzharylgan Mountains, to the southeast.

Here, a belt of Silurian extrusives is the widest at the north flank of a vast depression. The section is as follows:

1. Extrusives: liparitic porphyries, light-yellow and greenish-yellow albitophyres; to a smaller extent, lenses of gray-green and purple andesite porphyries. Thin layers of tuffs and tuffaceous sandstones. Some 50 to 150 m away along the strike, the volcanic rocks change to argillites and metasiltstones, slaty, light gray and yellowish gray, with tuff intercalations. The argillites and siltstones carry graptolites: *Retiolites geinitzianus* Barr., *Monograptus marri* Perner, *Spirograptus spiralis* Geinitz, *Spirograptus* sp., *Sp. ex gr. exiguus* Nicholson. The overall thickness, 880 m.

2. Porphyrites and liparitic porphyries, dark gray, purple, and red. Some conglomerate lenses with pebbles of red quartz porphyries. Thickness, 335 m.

3. A complex extrusive-sedimentary aggregate, consisting of liparitic porphyries, albitophyres with lenses and intercalations of tuffs, tuffogenous sandstones, conglomerates, argillites, and metasiltstones. Poorly preserved remains of brachiopods and trilobites were found in the tuffaceous sandstones. Thickness, 1480 m.

4. Porphyrites and their tuffs, dark gray, greenish-gray, purple. Thickness, 1150 m.

D₁ 5. Tuffs, tuffaceous sandstones, slaty, brown-red and light brown, with lenses of porphyrites and intercalations and lenses of gray cherty rock and fine-pebble conglomerates with pebbles of red liparitic porphyries. Thickness, from 375 to 750 m.

D₂ 6. Upper Devonian red quartz albitophyres, resting unconformably.

Going southeast, the character of the volcanic series remains the same, but its thickness sharply decreases. South of Mynaral, and east of the railroad, the following section is observed:

1. Extrusives: light gray and green liparitic porphyries, with lenses and intercalations of tuffs, and rare lenses of purple porphyries. Lying in the lower part of the stratum, there are lenses of light-colored sandy limestones, very poor in fauna. Thickness, 460 m.

2. Fine-pebble conglomerates, with pebbles of gray and green acid extrusives. Thickness, 80 to 260 m.

3. Tuffs and tuffaceous sandstones, gray to red-purple, thin bedded, with some por-

phyrites. Going upward, they change gradually to a complex agglomeration of porphyrites, tuffs, and red quartz porphyries. Thickness, 790 to 970 m.

4. Devonian red quartz albitophyres.

In both sections, the volcanic-sedimentary accumulations are a discrete complex, without any traces of breaks or unconformities. The lower part of this complex undoubtedly is Tarannonian; its upper age limit is not clear.

Wenlock-Ludow. Akkan limestone. A thickness of Wenlock and lower Ludlow limestones, here called the Akkan limestones, is traced for some 30 km from the south shore of Ak-Kerme Bay to the Karakamys massif. They are also present on the Ak-Kerme Peninsula.

In a locality on the south shore of Ak-Kerme Bay, where the railroad approaches the bay from the south, brachiopods were found in poorly stratified limestones, identified by T.B. Rukavishnikova as *Camarotoechia* sp., *Spirifer* (*Eospirifer*) *balchaischensis* Nikif., *Leptaena* ex gr. *rhomboidalis* Wilk., *Atrypa* ex gr. *reticularis* L., *Rhynchotreta cuneata* Dalm., *Anastrophia* aff. *internescens* Hall. According to T.B. Rukavishnikova, this assemblage belongs to the Wenlock stage.

At the base of the same ridge, and immediately west of the railroad (outcrop 329) a sequence is exposed, of interbedded granular limestones and yellow marls, 15 to 20 cm thick. They carry *Pentamerus* cf. *oblongiformis* Sow., *Lissatrypa kasachstanica* Boris., *Atrypa* sp., *A. reticularis* var. *dzewinogradensis* Kozl., *Plectatrypa* ex gr. *marginalis* Dalm., *Conchidium* sp. Also collected were such tabulates as *Halysites optimus* Kov., *Heliolites bohemicus* Wentzel, *H. lindstromi* Kov. (ident. by O.P. Kovalevskiy). This assemblage, occurring as it does above the slates with Tarannonian graptolites, should be taken as Wenlock, by its brachiopod content; this despite O.P. Kovalevskiy's statement that a similar assemblage of tabulata occurs in the Ludlow deposits, in the vicinity of Ak-Kerme Bay. To the northwest, on the north wing of the Ortansk anticline and farther on, as far as the Akkan Mountain, as well as on the Karaagach Peninsula, the Akkan limestones carry a Ludlow assemblage of brachiopods and tabulata. Thus, on the north shore of the Karaagach Peninsula (outcrop 701), T.B. Rukavishnikova recognized: *Conchidium* cf. *knightsi* Sow., *C. cf. vogulicum* Vern., *C. aff. tenuicosta* Hall et Wh., *Dolerorthis rustica* (Sow.), *Pentamerus* sp. Numerous *Heliolites* *tromi* Kov. and *H. bellus* Kov. were found along the

strike of the brachiopod limestones, in the same ridge. Nearer to Lake Balkhash, red-dish metasiltstones stretch in a band among the limestones; they carry graptolites, unfortunately too poorly preserved for more than generic identification (*Monograptus* sp., *Pristiograptus* sp.). The relationship between this finding and the assemblages of brachiopods and Tabulata remains obscure.

The Ludlow assemblage of genera is present in the Akkan limestones, on the north wing and on the northeast plunge of the Ortansk anticline. Here were found (outcrop 558) *Conchidium* cf. *tenuicosta* H. et W., *C.* cf. *knighti* Sow., *C.* cf. *vogulicum* Vern., *Atrypa* sp. and other genera (identified by T.B. Rukavishnikova). Alongside them were found Tabulata *Favosites bisingeri* M.E.H., *Halysites opimus* Kov., *Heliolites interstinctus* L., *H. bellus* Kov.

Finally, some 5 km northwest of Ak-Kerme Bay, and along the strike of the Akkan limestones, O.P. Kovalevskiy collected: *Favosites forbesi* M.E.H. var. *similis* Sok., *F. pseudoforbesi* Sok. var. *reflexibilis* Kov., *F. stepanovi* Kov., *F. sinuosus* Kov., *Parastriatopora mutabilis* Tschern. var. *balkhaschica* Kov., *Heliolites interstinctus* var. *sparsa* Kov. *Helioplasmolites nalivkini* Chekhovich.

These lists of genera prove the Wenlock and Ludlow age of the Akkan limestones. Their detailed stratigraphic differentiation is a task for the future.

On the southwestern shore of Ak-Kerme Bay, the Akkan limestones are overlain by multicolored argillites and metasiltstones, as much as 120 to 150 m thick. They are barren of organic remains. Apparently, they terminate the Silurian of the Ak-Kerme Bay area.

Devonian System

Lower Devonian. The Devonian opens with conglomerates of sand-cemented pebbles of variegated rocks, including the Akkan limestones. These conglomerates are best exposed on the plunge of the Ortan anticline, where they form a large field. To the west, in the Bzaul'da River valley, they change their character; here the pebbles are chiefly of Silurian metasiltstones and sandstones, with the limestone fragments lacking. Along their strike, the conglomerates are replaced by andesine-labradorite porphyries, interbedded with amygdaloid lavas as well as lenses and beds of tuffs and tuffaceous sandstones. In their general aspect and petrographic composition, they are very similar to the Silurian volcanics; an essential dif-

ference is the presence here of individual lenses of red-brown porphyries, attaining 300 m in length and 50 m in thickness. These liparitic porphyrites commonly contain pebbles of the conglomerates which form lentils and beds in the upper part of this volcanic-conglomeratic section.

This formation was found barren of organic remains. Only near the settlement of Karagach, west of the railroad curve, plant remains were found whose state of preservation precluded specific identification.

The Lower Devonian thickness varies from a few hundreds to 1,000 m.

Middle Devonian. Strongly nonconformable with rocks of various age. Thick liparitic porphyries and albitophyres, with a bed of tuffaceous sandstones and metasiltstones is present in the upper part. An imprint of *Gilboaphyton goldringiae* Arnold, characteristic of the upper Middle Devonian, was found in this bed by M.S. Bykova. The overall thickness of this upper Middle Devonian series reaches 1,000 m.

The following series is made of red argillites, metasiltstones, and conglomerates with lentils and horizons of variegated tuffs, in places light colored, banded; in others, dark, almost black. There are isolated lentils of light-colored limestones, as much as 3 m thick, barren of organic remains. The thickness of the series is no less than 700 m.

Finally, the youngest deposits, possibly Middle or Upper Devonian, make up a peculiar volcanic series consisting of intricately interrelated red liparitic porphyries and their tuffs, with lenses of dark augite porphyrites in acid extrusives. The thickness of this series is 300 to 400 m.

These three series represent large lenses lying en echelon to each other. Therefore, the overall Middle Devonian thickness cannot be determined by a simple addition of their thicknesses. Probably it does not exceed 1,000 m.

Carboniferous System

The Devonian volcanic section gives place to conglomerates and tuffs. Predominating in the pebbles are well-rounded fragments of red liparitic porphyries, from several centimeters to 1 m and larger.

In similar conglomerates to the south of the subject area, at the south end of Lake Balkhash, V.A. Khakhlov [9] found imprints of Upper Devonian flora; in sand lentils of this series, 2 km north of Mynaral, we

found quartzitelike sandstones with plant imprints identified by M. A. Senkevich as *Pteridorachis* sp., *Heteracidium* sp., *Lepidodendropsis* sp., *Knorria* sp. This assemblage implies either a Devonian or Carboniferous age for their emplacing rocks. Apparently, this bed belongs to the uppermost Devonian or to the Tournaisian Carboniferous stage.

This bed is overlain by calcareous sandstones and metasilstones with numerous brachiopods, *Productus deruptus* Koem., *P. dengisi* Nal., *P. magnus* M.W., *Spirifer tornacensis* Kon., *Sp. plenus* Hall, and others (ident. by G.R. Shishkina) suggesting an Ishim Carboniferous age.

Higher up, there lie sandstones and metasilstones filling the central part of the Karakamys syncline. These rocks carry poorly preserved plant remains. There are a few small lenses of limestones barren of organic remains.

It is not impossible that this rock section may turn out to be coal bearing, but this cannot be ascertained without digging and drilling.

INTRUSIVES

Intrusives of various ages are present in the Mynaral area. However, in most cases, their dating is arbitrary, done by analogy with similar formations in other intrusive massifs of Kazakhstan. The data extent make it possible to separate three intrusive types: Archean granite-gneisses, Caledonian tonalites, and early Hercynian granites of the Karakamys massif, with their vein series.

1. Archean granite-gneisses. Their exposures are observed 4 km east of the Karakamys massif, in the area of distribution of the Llandoverian conglomerates. The position of these granite-gneisses, the absence of any contact alterations in the enclosing rocks, as well as the presence of similar rocks in pebbles of Silurian conglomerates, make it possible to count them as pre-Silurian. The possibility of their belonging to a Precambrian basement high should not be ruled out. The rocks are represented by pink, coarse- to medium-grained granites, massive, locally slightly gneissic and cataclastic, strongly porphyritic in isolated regions. The granites are made up of tablets of intensely pink potassium feldspar (microcline), gray plagioclase (oligoclase No. 32), gray semitransparent quartz, and hornblende. Where the texture is porphyritic, the incrustations are of potassium feldspar and plagioclase. The rock is strongly altered: plagioclase

is nearly fully sericitized, potassium feldspar perthitized, hornblende is replaced by chlorite; quartz grains show cataclastic structure and have wavy extinction. Besides the coarse- and medium-grained granites, fine-grained granites were found in pebbles -- possibly a vein variety of coarse-grained granites, or else a hybrid formation. In their composition, the fine-grained granites are similar to the coarse grained, except for their grain size, their definite gneiss structure, and their greater biotite content.

2. Caledonian tonalites are represented by strongly mylonitized rocks. They make up a narrow body, oriented SW, as much as 3 km long and 100 to 150 m wide, running parallel to the projection of a large fault trending in the same direction. The position of this body, and a lack of natural intrusive contacts, suggest that the tonalites are a narrow Caledonian block along the fault. Similar rocks of known Caledonian age are known from the Bet-Pak-Dala Desert (Oguz-Tau massif). The rocks of that massif are represented by gray, tough, strongly mylonitized varieties. Quite discernible are tablets of white and rose feldspar, chiefly plagioclase (oligoclase), with a small amount of potassium feldspar; the quartz grains show distinct cataclastic structure, with hornblende replaced by chlorite and epidote. The rocks are strongly altered, chiefly by albitization and sericitization. The Caledonian granodiorites and gabbros are also observed in the western Karakamys, where they make up a block oriented NW, in an overall area of 70 square kilometers. Most of the exposed area is made up by granodiorites, with their edges marked by quartz diorites, diorites, and hornblende gabbros which are connected with the granodiorites by rapid but gradual transitions. The presence of taxitic structures, the rapid change in rocks over a small area, and an abundance of sphene and apatite suggest their hybrid origin. A study of the relationship between granodiorites and granites has revealed the presence of a sharp intrusive contact between them; this is in accordance with G.Z. Tsaplin's view of the granodiorites as an independent Caledonian intrusion.

3. Early Hercynian granites and their vein facies. These intrusions are represented by granites of the Karakamys and Dzhalgыз massifs. Only the Karakamys rocks are described here. The rocks of the other massif, externally similar to them, have not been studied in detail.

The Karakamys massif is located in the southeastern part of the desert and, contacting as it does the Precambrian and lower Paleozoic deposits, it presents a distinct body, trending northeast and limited by faults

striking northeast and northwest. The granites pierce the entire Paleozoic section, up to and including the Silurian, and are in actual contact with it. Therefore, the lower age limit of this intrusion seems to be post-Silurian. On the other hand, a little east of the Karakamys intrusion, the Upper Devonian and Lower Carboniferous carry gabbro-diabase and plagiogranite-porphyry dikes, running nearly meridionally, i.e., in the same direction as the similar-in-composition dikes of the Karakamys massif. Because of that, we assume the age of the Karakamys intrusion to be early Hercynian.

Usual rock phases and facies are recognized in the Karakamys massif. The intrusive phase is: 1) main intrusive facies -- biotite granites; 2) endocontact facies -- hornblende-biotite granites. A phase of complementary intrusions are small bodies of a granite or grano syenite composition. The vein rock phase is represented by rocks of both stages and by veins of rare metals. The Karakamys rocks are noted for their hybrid formations present both in the intrusives and in the complementary intrusions and veins.

Normal granites are the most common, accounting for about 85% of the Karakamys area. They are gray, light gray, rose, medium to coarse-grained rocks, locally porphyritic, with a various biotite content. They consist of tablets of white and gray plagioclase (oligoclase No. 25) 4 to 5 mm long, short crystals of rose potassium feldspar (microcline and orthoclase) up to 5 to 8 mm, biotite scales 2 to 3 mm wide, and gray quartz grains. The endocontact facies are represented by melanocratic, essentially biotitic, locally hornblende-biotite varieties, with light-colored mineral content as much 20% of rock volume. A characteristic feature of melanocratic granites is the presence of numerous biotite xenoliths, or else of feldspatized Archean crystalline schists, also an uneven distribution of colored minerals. The rocks are gray, dark, and red in color, and of porphyritic texture brought about by coarse incrustations of potassium feldspar, as much as 2.5 cm.

The contact metamorphism is unevenly expressed in the enclosing rocks, as hornblendization and weak granitization. The latter is observed only in the northwest contact where Archean rocks are developed. The Paleozoic rocks at the eastern intrusion contact underwent hornblendization, along a zone about 200 m wide. The Silurian and Devonian sandstones and metasiltstones are altered to biotite hornblendites. In the alteration of Silurian greenstones, amphibole hornblendites were formed, with the lime-stone lentils altered to garnet, amphibole-

garnet, and epidote lime-silicate hornblendites. The northern hornblendized contact zone is considerably smaller, not exceeding tens of meters.

Thus, the contact alterations, as a whole, are those of shallow depths. The hornblende facies are only locally complicated by feldspatization and granitization, the extent of which is negligible.

The complementary intrusions are represented by coarse- to medium-grained granites, syenites, and granosyenites. They definitely cut the main phase intrusives, but they precede all vein formations. In their relationship with the structural elements, two groups of complementary intrusives are recognized: 1) those associated with the endocontact of the massif and corresponding in their composition to leucocratic granites; exposed area from 1 to 24 km²; 2) those located along faults, and inconsistent in their composition; they are granites, granosyenites, and syenites. Their exposed areas are small, 2.5 km².

Compared with common granites of the Karakamys massif, the complementary intrusive granites are characterized by their more leucocratic composition, their pale rose hues, low biotite content, extreme heterogeneity of structures, especially in endocontacts, and their lack of oriented textures.

Vein rocks of the first stage include plagiogranites, vein granite, pegmatites, aplites, and orebearing scheelite veins. Most common are vein granites and aplites. The vein granites make up bodies of various size and thickness, mostly nearly flat, with a near latitudinal strike. The aplites are represented chiefly by thin veins running northwest, and ore usually steeply dipping.

Vein rocks of the second stage are represented by quartz syenites, alkaline granites, plagiogranite-porphyries, diorite-porphyrites, and gabbro-diabases. These rocks are unevenly distributed throughout the intrusive body. Most common are the dikes of plagiogranite-porphyries, diorite porphyries, and gabbro-diabases. These dikes are longer and definitely associated with the intrusive body; in the Paleozoic deposits, only a few of them are observed beyond the massif. The earliest representatives of this series of vein rocks are rare dikes of quartz syenites, followed by granite-porphyries and plagiogranite porphyries.

Among vein rocks of the second stage also belong the dikes of diorite-porphyrite and gabbro-diabase. All observed exposures of these rocks are located chiefly in the

eastern half of the massif; and beyond it, to the south, where the dikes cut Ordovician, Silurian, and Lower and Middle Devonian deposits. In the northeastern part of the area, along the Lake Balkhash shore, diorite porphyrites cut the Lower Carboniferous deposits, thus building up a number of small, stock-like, intrusive bodies, and piling up two small massifs on the Mynaral Peninsula. The easterly of the two is the larger, spreading over about 2 km².

The rocks of this shore outcrop are gray, medium-grained, containing incrustations of plagioclase, quartz, and hornblende.

The most recent vein formation of the second stage are low-temperature quartz veins and quartzitization zones along the east contact of the massif.

TECTONICS

The subject area is located on the north wing of the large Burunta anticlinorium [5] and in the southern part of the West-Balkhash synclinorium [11]. Going from the southeast to northwest, Proterozoic and lower Paleozoic deposits gradually change to Carboniferous deposits, filling the Karakamys syncline. On this background, several narrow, elongated synclines and anticlines stand out, trending northwest and complicated by high angle faults (Figs. 2 and 3).

The largest anticlinal structures which expose Precambrian rocks in their middle parts, are the Terenkul' anticline and the Ak-Kerme anticlinal zone comprising the en echelon trending Ortansk and Mynaral anticlines.

Between the Ak-Kerme anticlinal zone and the Terenkul' anticline, there lies the large and complicated Karashingil' synclinal zone, with the Karaagach anticline stretching in its middle part. North of the Ak-Kerme anticlinal zone, there lies a vast area of Devonian deposits, uniformly dipping north, toward the Karakamys syncline. We have named this structure, the Mynaral monoclinical block. Overturning to the north is characteristic for the majority of anticlinal and synclinal structures (of the area), which is well expressed in a difference between dips of the north and south wings. Below a brief description of the several structures is given.

1. The Kuyandy-Uzek syncline is a large synclinal fold. Reefian (?) deposits, immediately underlying the Ordovician of its south limb, dip N - 50° to 70° - E, at 40°; their dips on the north wing are flatter, S - 0 to 20° - W, at 18° to 20°. Its middle part is com-

plicated by numerous small folds, bringing siliceous reef rocks to the Ordovician rocks. Because the dark Ordovician schists are here transgressive upon the reef, (both being) represented by rocks of a similar type, their differentiation is not always feasible. The syncline is complicated by a north-west trending fault, well defined by a displacement of siliceous reef ridges, very distinct on aerial maps and traceable for over 20 km.

2. The Terenkul' anticline is a complex structure made up of reef-Lower Paleozoic schists. Its south wing is comparatively flat; its north wing is disturbed over fairly long stretches, and complicated by faults, crushing zones, and auxiliary folds. Over considerable distances, the beds are overturned. The biggest fault brings in contact between reef and Silurian deposits.

3. Karashingil' synclinal zone comprises two synclines separated by the Karaagach anticline. The latter is marked by a belt of Silurian rocks (Tarannonian, Akkan limestones, and overlying red beds) among the Lower Devonian volcanic clastics. On the peninsula, the Karaagach anticline is complicated by several secondary folds. The Dzhilymdin syncline, to the south, is built up, in its central part, by flat Devonian conglomerates. On the north wings, porphyrites emerge from under them, dipping S-10° - E, at 50° to 55°. On the south wing, the volcanic deposits are replaced by a series of red tuffaceous shales.

The second, the Kaysun'-Kamys syncline, is best defined at the southeastern point of Ak-Kerme Bay; here its central part is filled by Devonian conglomerates, forming distinct relief steps. On the south wing, the dips are N - 0 to 5° - E, at 50° to 70°; on the north - S - 0 to 5° - W, at 30° to 40°. Northeast of the Dzhilymda mud flats, a complicated fault system is developed, with the synclinal structure of individual blocks only noticeable in the Devonian conglomerate ridges.

4. Ortansk anticline is located on the south shore of Ak-Kerme Bay, and is built up in its middle part, by Ordovician rocks. It is nearly symmetrical, with Ordovician dips on its south wing, S - 20° to 30° - W, of 50° to 55°; on the north wing, N - 20° - E, of 60° to 70°. The anticline plunges rapidly to the northwest, but can be traced farther on, almost as far as the Mynaral-Dzhimtau road, by the Devonian conglomerates forming here a well-defined arch. On the southwest and south, the anticline is cut by faults where Ordovician deposits contact the Devonian. A major fault, trending northwest, splits the anticline into east

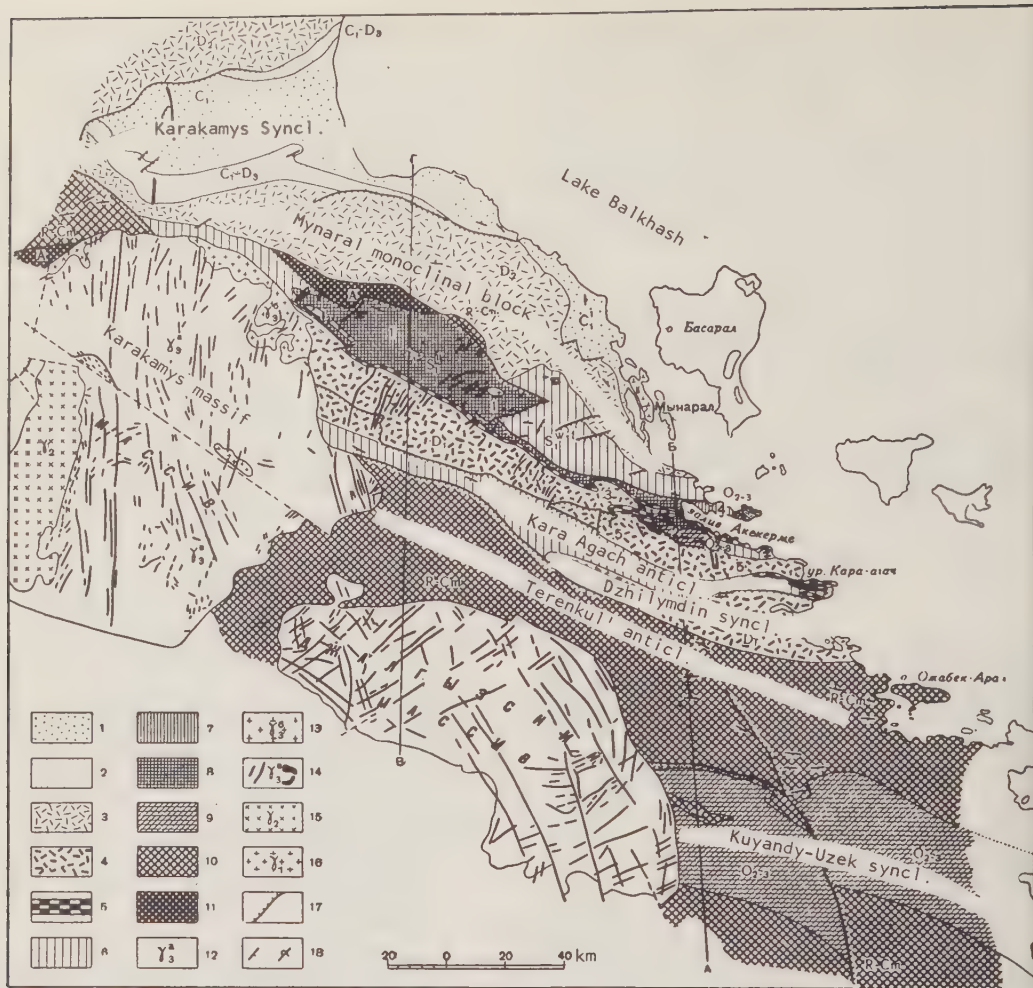


FIGURE 2. Structural scheme of the Mynaral area, west of Lake Balkhash

1 -- Lower Carboniferous sandstones and shales; 2 -- Lower Carboniferous-Upper Devonian sandstones; 3 -- Middle Devonian quartz albitophyes, conglomerates, and sandstones; 4 -- Lower Devonian porphyrites, tuffs, sandstones, conglomerates, schists; 5 -- Lower Ludlow-Wenlock, Akkan limestone; 6 -- Wenlock-Tarannonian, porphyrites, schists, sandstones, conglomerates; 7 -- undifferentiated Silurian of the Ak-Kerme Peninsula; 8 -- Llandoveryan conglomerates, siliceous schists, acid extrusives; 9 -- Ordovician sandstones, conglomerates, cherty schists, metasiltstones; 10 -- Cambrian-Reef, schists and siliceous rocks; 11 -- Archean (?) crystalline schists and gneisses; 12 -- granites of the main phase of early Hercynian complex; 13 -- complementary intrusives (granites and granosyenites); 14 -- vein rocks of first and second stages, and quartzitization zones (aplites, fine-grained granites, quartz syenites, granite-porphyrries, gabbro-diabases, and diorite-porphyrries); 15 -- granodiorites, tonalites, diorites and gabbros of the Caledonian complex; 16 -- granites and granite-gneisses of the Archean complex; 17 -- faults, strikes and dips.

Figures on map: 1 -- Mynaral anticline; 2 -- Ortansk anticline; 3 -- Kovalevsk syncline; 4 -- Ak-Kerme Peninsula structure; 5 -- Kuysun'-Kamys syncline.

and west parts.

Along this fault, Ordovician (Llandoveryan) deposits are brought in contact with the Silurian (Tarannon).

5. The Mynaral anticline is a broad, gentle arch made up of Mynaral' conglomerates which dip on its southeast wing, N 35° to 40° - E, at 15°; and due south, at 20°, on its southwest wing. In a fault zone along the northeast wing, conglomerates and

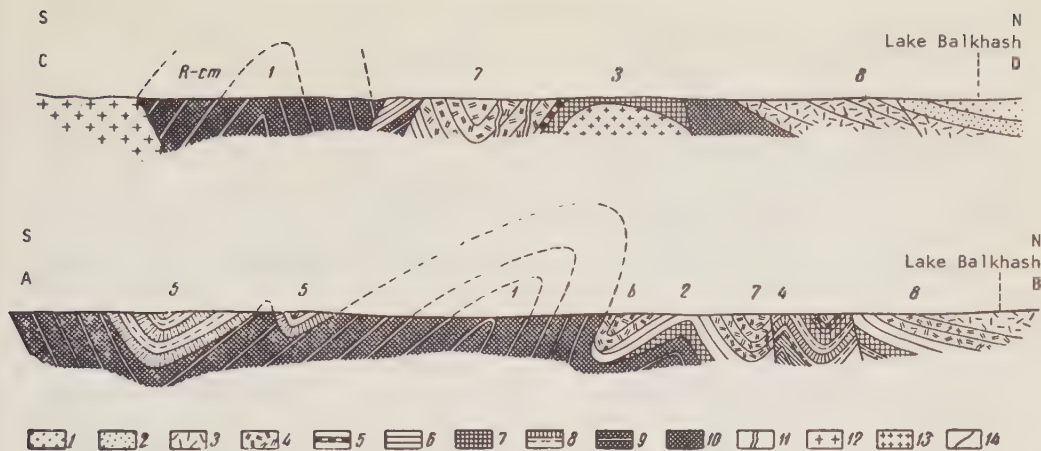


FIGURE 3. Diagrammatic cross sections of the Mynaral area, along lines A-B and C-D

1 -- Lower Carboniferous; 2 -- Lower Carboniferous-Upper Devonian; 3 -- Middle Devonian; 4 -- Lower Devonian; 5 -- Lower Ludlow-Wenlock, Akkan limestone; 6 -- Wenlock-Taranonion; 7 -- Llandoveryian; 8 -- Ordovician; 9 -- Lower Paleozoic-Proterozoic; 10 -- Archean; 11 -- diabbases; 12 -- Hercynian granites; 13 -- Caledonian granites; 14 -- faults.

overlying arenaceous deposits are in contact with the uplifted block of Precambrian rocks; on the southwest wing, they are progressively overlain by the Akkan Silurian limestones. On the latitude of Mynaral, the arch of the Mynaral anticline is separated by faults of the Mynaral monoclinical block. Only a small segment of the south wing has been left of the anticline; it is represented by Llandoveryian rocks emerging from under the Akkan limestones, as an outcrop. A projection of the folds may be seen in a complicated system of the Ak-Kerme Peninsula disturbances which are dealt with in a paper by B.M. Keller [3].

6. The Mynaral monoclinical block is made up of Silurian and Devonian rocks dipping northeast in the eastern part and north in the western part -- first steeply, as much as 70° ; then flattening down to 30° to 40° in the Devonian. Beside the regional fault, the south fringe of the Mynaral block is complicated by a series of northeast-running cross faults, which brought about a small displacement of Devonian rocks.

7. The Karakamys syncline is a gentle structure made of Carboniferous deposits. The syncline is well defined in the west and south, by a bed of Ishim limy sandstones, dipping on the south wing, N- 25° -E, at 15° to 20° . The dips in the central part of the syncline do not exceed 10° . Both on the north and on the south limbs, the Devonian-Carboniferous contact is marked by faults, running almost latitudinally. Two fault systems are identified in the area. The faults of the first system are either sublatitudinal

or else trending WNW, and are commonly associated with anticlinal wings. The best defined are the fault cutting the southeast wing of the Terenkul' and the southwest limb of the Ortansk synclines. Apparently, they are thrusts, with the upper blocks displaced toward the Ak-Kerme anticlinal zone (see Fig. 2).

The faults of the other system trend to the northeast. They are well defined by a displacement of deposits in the surface relief, and they stand out on aerial maps; the displacement along them usually is not over a few hundred meters.

Finally, northwest-running faults are present in the eastern part of the area; apparently, they fringe the Karakamys granite massif. Along these faults, western blocks ride over the eastern.

It should be noted that the systems of diabase and other dikes trend, as a rule, northeast and are especially well developed within the northwestern Ak-Kerme anticlinal belt. Some connection between the faults and the vein intrusions is not to be questioned. It appears that the tectonic stressed which brought about the faults, were also instrumental in the origin of large fissures, running northeast, subsequently filled by vein rocks.

HISTORY OF THE STRUCTURE AND MAGMATISM DEVELOPMENT

In the course of all its geologic history,

the Ak-Kerme Bay area was a stable province of comparatively gentle downwarping, complicated by block faulting and by a differential movement of individual blocks.

After the emplacement of the Archean age granites and the deposition of thick Proterozoic-Cambrian arenno-argillaceous rocks, a general uplift took place, and a major pre-Ordovician schists persist within the Terenkul' anticline, they are fully removed from the north wing of the Mynaral' anticline where Silurian deposits rest directly upon reef deposits.

The Ordovician witnessed a fair degree of differentiation in the movement of various parts of the area. While a thick, uniform sequence of sandstones and shales was being deposited in the Kuyanda-Uzek syncline, the Ortan anticline area and the Ak-Kerme Peninsula received clastic terrigenous sediments, relatively thin. A break on the Ordovician-Silurian boundary is well marked by the Llandoverian Mynaral' conglomerates, but there are no traces of angular unconformities at the Silurian boundary.

Silurian is represented by shallow water volcanic-clastic and reef facies. The difference in the movement of the individual blocks is noticeable here, as well. Going from the northwest to southeast, one notices a definite thinning of the volcanic facies and their replacement by the reef and clastic (Fig. 4). In the central part of the Mynaral' monoclinical block, the Silurian volcanic clastics are thousands of meters thick. On the Ak-Kerme Peninsula, but a few kilometers away, they are fully replaced by a thin limestone-marl section.

The same regularity is well traced in the Devonian deposits (Fig. 5). Thick Lower Devonian volcanic-clastics in the western part of the Kuysun'-Kamys syncline, changed to thin conglomerates and sandstones, locally with plant imprints, on the Karaagach Peninsula and the south limb of the Dzhiylmdin syncline. In the Middle Carboniferous, basic extrusives changed to the acid, with the volcanic accumulations going on very unevenly, resulting in the formation of immense lenticular bodies.

During Early Carboniferous time, the area was differentiated into local uplifts and broad, gentle downwarps where shallow-water arenno-argillaceous deposits were accumulated, with conditions locally favorable for coal formation.

Apparently, here belongs the emplacement of early-Hercynian coarse-granite massifs which pierced and metamorphosed the Lower

Devonian rocks; their vein series cuts the Lower Carboniferous, as well.

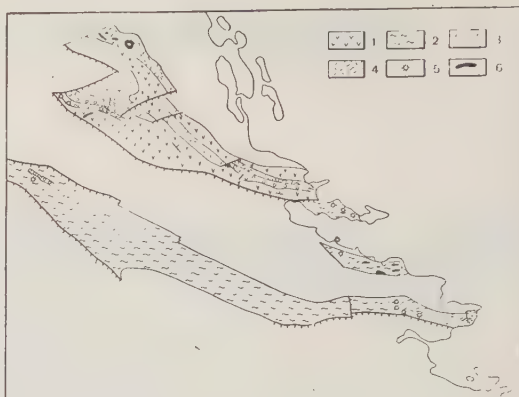


FIGURE 4. Petrographic composition of Silurian rocks (Wenlock-Tarannonian) exposed in the Ak-Kerme Bay area.

1 -- porphyrites; 2 -- schists, siliceous schists, metasiltstones; 3 -- conglomerates; 4 -- tuffs; 5 -- localities of Tarannonian graptolites; 6 -- diabase dikes.



FIGURE 5. Petrographic composition of Lower Devonian rocks exposed in the Ak-Kerme bay area.

1 -- conglomerates; 2 -- porphyrites; 3 -- schists and sandstones.

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PRINCIPLES OF PALEOFLOREAL DIFFERENTIATION OF CENOZOIC DEPOSITS IN THE KAZAKHSTAN AND ADJOINING PARTS OF THE WEST SIBERIAN PLAIN

by

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For the purpose of floral statistics, those plant genera should be used which, as systematic units of a higher rank, are better differentiated from each other, and whose distinctive features are more ancient and more persistent.

V. Shafer [27]

For the most efficient use of spore-pollen data in the study of the stratigraphy of Kazakhstan and its Cenozoic fauna much previously processed material was restudied in the light of new theory.

The areas of investigations are located in the northern Aral region, southern part of the Turgay downwarp, parts of Kara-Tau (vicinity of the Turkestan mountains), the Pavlodar Irtysh region, and in the southern West Siberian plain.

The geologic history of these regions is fairly similar, as is their paleogeography during the Paleogene, Neogene, and Quaternary.

Their geologic structure is dealt with, in considerable detail, in a number of individual and joint papers by A.L. Yanshin [28], K.V. Nikiforova [21], N.K. Ovechkin [22], V.V. Lavrov [19], Ye. P. Boytsova [5, 6], S.B. Shatskiy [25], and others; and there is no need to review each author's opinion, inasmuch as all extant classifications were reviewed by the All-Soviet Conference on a unified stratigraphy for Siberia, held in Leningrad, January 1956, and compiled on the basis of the latest data on paleoflora and fossil fauna. This includes, as appendices, all questions of stratigraphy of a controversial nature, or which need additional effort, or which answers only conditionally the purposes of geologic mapping.¹

According to this unified stratigraphy, the generalized Cenozoic section for the Trans-Ural plains (south part) is as follows (Fig. 1). The purpose of our study of the spore-pollen assemblages from all of the named regions, is to establish the most characteristic features for each, in the general aspect of their Cenozoic flora, and to obtain a basis for correlation of contemporaneous deposits.

Key sections, studied in the near-Aral area, are well characterized by marine (Paleogene) and continental (Paleogene-Neogene) fauna. The Turgay deposits are rich both in flora and fauna; in the Irtysh region, the continental Oligocene, Neogene, and Quaternary deposits also carry a fauna; only the sediments of the southern West Siberian plain are poor both in flora and fauna. However, they are correlative with the western sections, by their lithology and by spore-pollen data.

Furthermore, continental deposits of the more northerly part of the West Siberian plain are rich in flora beds among which of particular interest are those carrying seeds and leaves (localities along the Tara, Tyma, Kizak, Bicha-Turtas, and other rivers).

include the age determination of the bauxites from the east flank of the Turgay downwarp, and for the so-called "kushuk" beds with flora, of South Turgay (the flora has been identified as Miocene whereas the fauna suggests an Oligocene-Miocene age), and a number of others.

¹Specifically, these controversial topics in-

Age, type sediments		Series	Lithology	Paleontological reason
Q	Continental deposits	Quaternary deposits	Sands, sandy soils, clays, clay soils, peats, lacustrine clays, river-channel alluvium	Mammal fauna, mollusks, pollen, fruits, seeds
N ₁₋₂		Pavlodar	Sands, alternating clays and sands	Irtysk <u>hipparion</u> fauna
N ₁		Aral	Lacustrine and brackish-water deposits, clays with manganese spherules	<u>Corbula</u> fauna, mastodons, mammalian fauna of Agyspa, Kalkaman, Kushuk, Zhilanchik-2; <u>Aceratherium lienense</u> , <u>Brachipotherium</u>
Pg ₃		Chagray	Multicolored deposits, coarse clastic and arenol-argillaceous material	Zhilanchik-1 fauna
Pg ₃ ²		Chiliktin	Clays, cross-bedded sands, kaolin clays, multicolored clays. Sandstones with oolitic iron ores. Lignites.	<u>Indricotherium asiaticum</u> mammal fauna, pollen, land turtles, rich leafy flora: <u>Pristinotherium</u>
		Kutanbulak		
Pg ₃ ¹	Chiefly marine Continental marine	Chegan	Stratified clays with sideritic lentils	Mollusk fauna, pollen flora, and microscopically poor plant remains
Pg ₂ ³		Saksaul	Tough sandy clay, sands, sandstones	Marine fauna (A.L., Yanshin, 1943)
Pg ₂₋₃ ²⁻³		Tasaran	Sandy clays, glauconitic sandstones, sands, opoks (porous siliceous rock), opok clays	Foraminifera, diatoms, pollen, leaf imprints
Pg ₁₋₂		Suzak stage. Undifferentiated Lower Paleogene	Clays with plant remains. Bauxitic deposits of Ashu-Tasta. Sands, sandy soils, micaceous clays	Fauna, pollen
Pg ₁		Talits		Pollen

FIGURE 1. Generalized section of marine and continental deposits for the northern Aral area, Pavlodar Irtysch region, West Siberian Plain, and Turgay.

It would be difficult to name areas other than Turgay and West Siberia, which have been dealt with in so many published papers on microflora, and on pollen analysis, in recent years.

Only the most important are listed here: a paper by V.S. Kornilova [15] in which the author separates two types from the general assemblage of continental floras - the "Turgai" type, temperate, with an admixture of tropical xerophytes ("shintuzsay" and "bolatam" assemblages), and the "Aquitanian" type, corresponding to the upper Oligocene continental deposits; also a summary by the same author [16] giving the first roster of Paleogene floras of Turgay and the Aral area, on the basis of leaf imprints and pollen.

Of note is a work by L.N. Rzhannikova [23], describing the characteristic assemblages and their dominant genera, for each series of the continental Oligocene of the Turgay coal measures.

Extremely interesting are the papers by L. Yu. Budantsev [8, 9] on the Paleogene leafy floras of Turgay and the Irtysh area; they provide the history of the development of the Paleogene flora for these regions, separating three major stages (two Eocene and one Oligocene). Finally, there are the works by E.P. Boytsova [5, 6, 7], in which the author separates, by pollen and spores, the index spore-pollen assemblages differentiating the Upper Cretaceous and Tertiary deposits of Turgay.

Still, despite all the works directly or indirectly dealing with the sequence of floral development of the Trans-Urals, and with the stratigraphic position of these floras, the precise criteria for their exact age are, as yet, lacking.

A method of flora analysis will be described which we deem the most correct and the most consistent for determining the boundaries between the several fauna, in order to determine their stratigraphic position.

SPORE-POLLEN ASSEMBLAGES

The first and the basic stage in the study of sedimentary deposits by spore-pollen analysis is a statistical count of pollen and spore forms, in stratified key sections.

Such investigations imply the carrying out of mass, serial analyses and a determination of percent content for the main groups (gymnosperms, angiosperms, spores), and for individual components of each group.

In this process, the possibility cannot be ruled out, of considerable divergences in the percent content for assemblages from contemporaneous but facially different deposits. However, by correlation, it is possible to discern similarity in the character of the percent-content curves for each component of the groups, in the contemporaneous assemblage of a region, and to correlate them with assemblages from distant sections.

As a result of such correlations, a series of curves have here been developed, characterizing in their most general features the entire Cenozoic section of the subject regions. On the average, these type curves - if they may be so named - are as shown on Figure 2, with slight deviations, one way or another.

The oldest known Tertiary deposits (Suzak stage of the Kara-Tau) carry assemblages consisting almost entirely of angiosperm pollen, the best represented being the families of Myrtaceae, Myricaceae, genus *Conacomyrica* (?), *Eucalyptus*. Very rare is pollen of the genera *Rhus*, *Labordia* (fam. Loganiaceae) and fam. *Proteaceae*. Virtually absent are the genera *Alnus*, *Betula*, where present in all cases are pollen grains of problematical triporate angiosperm pollen, chiefly from extinct plants. The German scientists, Tomson and Pflug [29], and others, relegate this pollen to the synthetic genera *Extratriporeopollenites* Pflug, *Trudopollis* Pfl., etc. Various species of this pollen are widely developed in lower Paleogene spectra of the south part of European U.S.S.R., Western Europe, Turgay, Kazakhstan. In the more easterly part of the U.S.S.R., it is less common or lacking.

The content of gymnosperms is usually 5% to 10%; they are lacking in some beds. upper Eocene assemblages (Tasaran and Saksaul series) are also poor in gymnosperm pollen, although their content locally attains 30%. The spores do not exceed 5% to 25%, with the total angiosperm pollen ranging from 40% to 60%. Important among the gymnosperms are the families *Cycadaceae*, *Araucaraceae*, *Podocarpaceae*, *Pinaceae* (up to 20% of total gymnosperms). The pollen of the family *Penaceae* is important in all Eocene deposits, but its composition varies vertically [12, 13]. The Kazakhstan Eocene is characterized by a comparatively large content and variety of the species of genus *Cedrus*. However, it virtually lacks the pollen of genera *Taxodium* and *Tsuga*.

Eocene assemblages of the Tasaran and Saksaul series differ considerably in the composition of their angiosperm pollen. The Tasaran assemblages contain, among other angiosperms, the pollen of *Ebenaceae*, *Lauraceae*, *Proteaceae*, *Palmae*, *Trudopollis* Pfl.

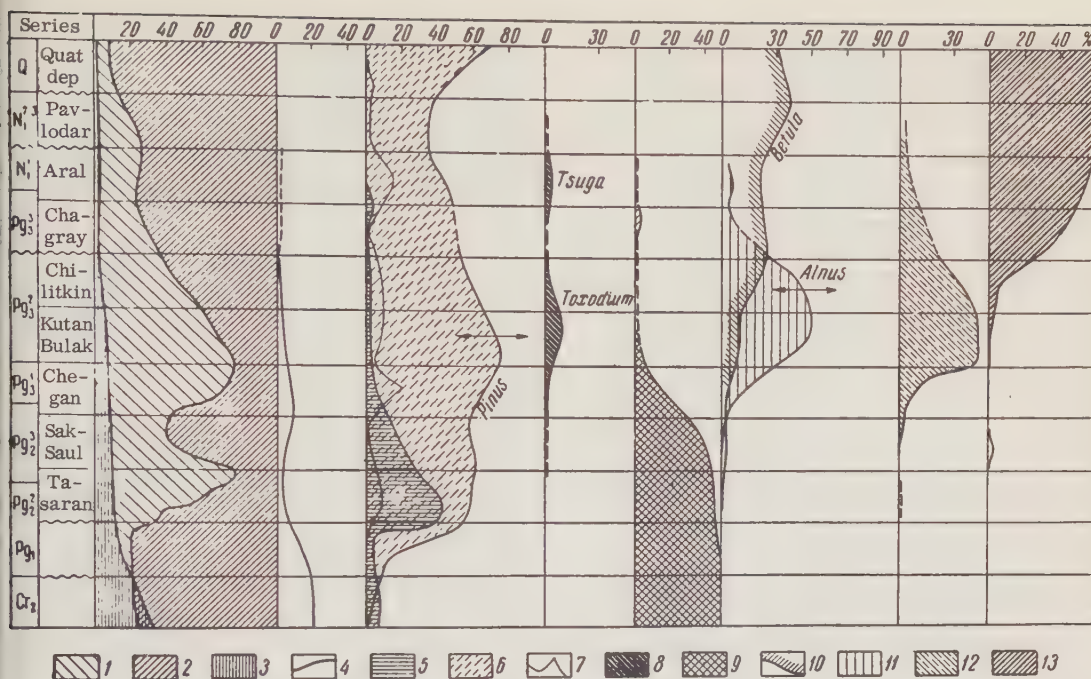


FIGURE 2. Generalized diagram of percent content for spore-pollen assemblage-content ratios, from the Cenozoic of the Trans-Uralian plains.

1 -- total gymnosperm pollen; 2 -- total angiosperm pollen; 3 -- total spores; 4 -- Cycadaceae, Ginkgoaceae, Araucariaceae; 5 -- *Cedrus*; 6 -- *Pinus*; 7 -- *Picea*; 8 -- *Taxodium*; 9 -- total pollen of subtropical plants and undefined pollen, type "Leguminosae"; 10 -- Betulaceae; 11 -- *Alnus*; 12 -- total pollen of broad-leaved annuals; 13 -- total pollen of grasses.

Nearly all of the Saksaul assemblages are enriched by the genera *Casaurina*, *Quercus*, *Alhagi*, *Castanea*, *Nitraria*, *Ferula*, and by representatives of various genera of the families Leguminosae, Chenopodiaceae, Goodeniaceae, Moraceae, Euphorbiaceae. These assemblages also contain the pollen of the synthetic genus *Extratrirporopollenites* Pfl. Practically lacking is the pollen of broadleaved annuals, with the exception of the uppermost beds of this series, at its boundary with the Chegan. Of a somewhat different aspect are assemblages of the Chegan series (upper Eocene-lower Oligocene), which reflect a mixed flora represented by subtropical elements with an admixture of the temperate. The percent-content curves for subtropical species show a definite decrease for gymnosperms, in general, and for the genera *Cedrus* and *Podocarpus*, in particular.

Common among the angiosperms are representatives of the genera *Alnus*, *Betula*, *Carpinus*, *Tilia*, *Acer*, *Eagus*, *Elmus*, *Ilex*, and others. The number of these genera is such as to be reflected by a curve. In the West Siberian and Irtysh assemblages, the

presence of the elements of temperate deciduous flora is considerably greater than it is in the contemporaneous Trans-Uralian and Turgay assemblages. Among the most common genera (represented by different species) in the Chegansk spectra are *Rhus*, *Nyssa*, *Alnus*, *Tilia*, *Castanea*, *Carya*, *Carpinus*, and the families Araliaceae, Moraceae, Euphorbiaceae. Still preserved in the lower beds of this series are elements of an arid flora, commonly with Chenopodiaceae, Moraceae, *Ephedra*, Euphorbiaceae, also *Palmae* (?).

Very distinct are some assemblages from the continental Oligocene; they are characterized by a considerable rise in the pollen curve for gymnosperms, whose numbers increase generally at the expense of the genus *Pinus*, here represented by various species. Especially widespread are species of the genera *Strobilus*, *Taeda*, *Cembrae*. The genus *Taxodium* is especially well developed in middle Oligocene sections (up to 40%). The genus *Tsuga* also makes its appearance here.

Especially abundant among the angiosperms,

is the pollen of a group of genera comprising the so-called temperate Turgay flora with Alnus, Pterocarya, Acer, Juglans, Nyssa, Betula, Carpinus, Ulmus.

The number of Araliaceae, Rhus, Myrtaceae is still important in the lower middle Oligocene, but they are of no significance or lacking in its middle part. Middle Oligocene spectra are distinguished by their rich pollen content of various species of the genera Alnus, Pterocarya, Juglans. Assemblages from upper Oligocene deposits usually contain less gymnosperm pollen, with the pollen of the genera Cedrus and Podocarpus only in a few places. Representatives of the genus Taxodium are fewer. The angiosperms are represented chiefly by species of the genera Betula, Alnus, Ilex, and others, with Pterocarya and Juglans present; the pollen of meadow-steppe grasses appear represented by the families Umbelliferae, Labiatae, Gramineae, Compositae, etc. Assemblage types differ: they represent either forest vegetation (Turgay) or that of open landscapes (Aral area), or else of tugay forest habitats (West Siberia). Representatives of marsh-lacustrine flora make their appearance as grass pollen: Sparganium, Potamogeton, Nymphaeaceae, etc. The number of subtropical xerophytes is either insignificant, or not present at all.

In deposits characterized by a lower Miocene fauna with Mastodon, Dicroceros, Aralotherium, also Corbula helmersenii, the spore-pollen content differ in composition. In the gypsiferous greenish-gray clays with ferro-manganese nodules, flora remains are poor, and the assemblages usually suggest an open landscape overgrown by many grasses, and with a smaller representation of wood plants, such as Betula, Alnus, Tilia, Pinus, etc.

Humus clays in the northwestern Aral area, locality Kuzhasay (Aral series of A.L. Yanshin, 1938), carry an excellent forest assemblage very similar to the middle Oligocene assemblages in its composition of both gymnosperm and angiosperm genera. This assemblage differs but little from those of the so-called Kushuk beds of Turgay, representing a clayey facies of the Chagray (Naurzum series of Turgay) series where a rich lower Miocene-upper Oligocene mammal fauna has been found, with Aceratherium auralienense, Brachipotherium, Indricotherium sp. The higher Tertiary beds of the Trans-Uralian plains are usually poor in flora, and their assemblages are monotonous.

In formations with Hipparion fauna, and in their areno-argillaceous correlatives, the assemblages are represented chiefly by grasses, with Chenopodiaceae, Ephedra,

Gramineae, Artemisia, Umbelliferae. The admixture of woody plants pollen does not exceed 10% to 15% and contains the genera Pinus, Picea, Taxodium, Tsuga. Thus, the Miocene-Pliocene assemblages of the Hipparion beds suggest a temperate flora, almost fully devoid of subtropical elements, and represented as a whole by open-habitat plants.

The Quaternary assemblages are still more monotonous in the number of representative genera and usually reflects vegetation of open habitat, with but an insignificant amount of woody-plant pollen (Alnus, Betula, Pinus), represented by modern species, probably localized.

Such typical spore-pollen assemblage, as distributed in the stratigraphic sequence, is characteristic for Tertiary deposits in the area from the northern Aral to the Yenisey ridge, across the southern Urals, Turgay, the Irtysh area, and southern West Siberia.

As a result of the spore-pollen assemblage analysis, and of a correlation of the data of macroscopic remains from sections whose stratigraphic position is clear, a general history of the Cenozoic vegetation cover is established and found to be amazingly orderly.

This sequence appears to be as follows:

1. Paleocene-Eocene: flora, subtropical with tropical elements; vegetation type, forest.
2. Upper Eocene: flora, subtropical, with elements of xerophyte desert (?) associations.
3. Lower Oligocene: flora subtropical, with an admixture of deciduous temperate elements. Vegetation, forest type.
4. Middle Oligocene: flora temperate with an admixture of subtropical relicts from the Eocene. Vegetation, forest, mixed coniferous-broadleaf, coniferous, and broadleaf.
5. Upper Oligocene-lower Miocene: flora, temperate. Diversified vegetation: chiefly forest, mixed coniferous-broadleaf, for upper Oligocene; open-habitat type with tugay type forest, for lower Miocene.
6. Miocene and Pliocene: flora, temperate. Vegetation, chiefly open habitat, with birch groves and local forests.
7. Quaternary: flora, temperate. Open-habitat vegetation, somewhat similar to the present, for the subject areas. The incidence of the forest element is short-lived and sporadic, being associated with bottom beds.

This general spore-pollen orientation is excellently marked in all spore-pollen assemblages for the regions names. A testimony to its merit is its general recognition by the students of the Trans-Uralian Cenozoic; the only exception is taken by a group of collaborators of the West Siberian Geological Administration - A.G. Kovalevskaya [14] and G.A. Baluyeva [1] - who relegate the subtropical Chegan flora to the upper Oligocene, on the basis that this flora, enriched as they are by the "Turgay" element, belong to the "Aquitanian" complex as designated by A.N. Krishtofovich, in 1941.

The second controversial thesis propounded by these investigators, that of an upper Oligocene-Miocene age of the floras associated with the *Indricotherium*-fauna deposits, is an essentially unfounded conclusion. Without pausing for a discussion of this question, I will only note that the Chegan flora is associated with a marine upper Eocene and lower Oligocene fauna; therefore it is considerably older than is assumed by A.G. Kovalevskaya and G.A. Baluyeva.

Moreover, it is essentially wrong to call this flora temperate, since its xerophytic subtropical elements considerably outweigh the holarctic temperate. On the other hand, the appearance of a number of species of the genera which subsequently became well developed in the middle Oligocene flora, suggests that the Chegan flora should be taken as transitional to a new and subsequently developed complex of middle Oligocene "Turgay" floras.

AN ATTEMPT AT THE ANALYSIS OF GEOGRAPHICAL ELEMENTS OF THE CENOZOIC FLORA FROM THE SOUTH TRANS-URALIAN PLAINS

In the process of analysis of the material, it became clear that, besides the apparent generic differences in both the gymnosperm and angiosperm plants, the flora of each series contains separate groups of fossil genera and species, whose present geographic distribution is different. In the majority of cases, the present habitat of these genera and species is far removed from their Paleogene and Neogene sites.

These groups of genera and their species come and go in stratigraphically different beds.

Because of the fact that a differentiation of habitat, or their localization in isolated botanical-geographical provinces, was the result of considerable changes in the physical-geographical environment, particularly

in climate and in the configuration and size of marine basins, we deem it expedient to analyse the relationship between the geographical elements of a fossil flora and to trace them both vertically and laterally.

Such studies are not new. V. Shafer [26] engaged in them, in his analysis of the Pliocene Chorshtyn flora. He used species, as is normal for modern and near-modern flora. In 1957, V.P. Grichuk also analysed the geographical elements, in connection with the problem of the lower boundary of the Quaternary, wherein he demonstrated a step-by-step disappearance of the tropical elements of the flora, from the top of the Miocene to and including the Pliocene.

Besides the pollen assemblages, the most complete floral rosters of leaf imprints were used for each bed. They were taken from papers by V.I. Baranov [2, 3], V.S. Kornilova [15, 16], L. Yu. Budantsev [8, 9], V. Sukhov [24], M.G. Gorbunov [10, 11], A.A. Larishchev [20], and other authors. The material was taken only from those papers dealing with the localities whose stratigraphic position coincided with that of our pollen-bearing beds.

About 300 species of angiosperms belonging to 170 genera, and some 80 to 100 species of gymnosperms belonging to 30 genera, are represented in the Cenozoic flora of the Aral area, Turgay, Irtysh area, and the southern West Siberian plain. This count is not exact, of course; it is quite possible that some specimens, identified by their pollen and other properties as different species of the same genus, may be in fact the same species. Moreover, any catalogue of pollen assemblages always contains a group of unidentified specimens whose taxonomic position has not been determined. They are mostly species of extinct genera.

Certain genera, represented by a few species, appear as solitary findings, and the duration of their development throughout the subject area is short (*Lauraceae*, *Palmae*, *Aralia*, *Eucalyptus*, and others). A large number of genera appear at the base of the Paleogene and persist up to the Pliocene, in a modified specific composition (the genera *Pinus*, *Carpinus*, *Myrica*, and others, and the family *Chenopodiaceae*).

Turning now to the modern habitat of the genera now known from the Cenozoic flora, we note some curious regularities which suggest that the change in the composition of fossil floras occurs as a result of a shifting of the distribution boundaries for entire generic groups which are now characterized by a definite geographic distribution.

Staying within the framework of the established technique of dividing the globe into floral zones, it is possible to divide all the genera known from the Cenozoic of the Trans-Uralian plains, into the following groups, by means of their botanical-geographical properties:

I. Widely distributed genera whose habitats, both differentiated and not, are essentially confined to the holarctic botanical-geographic province; also cosmopolitan genera, scattered all over the world.

II. Holarctic genera, whose habitats do not extend beyond the south boundary of the holarctic floral province.

III. Holantarctic-paleoneotropical genera, confined chiefly to the south boundary of the holarctic floral province.

IV. Paleoneotropical genera, with their habitats confined to the neo- or paleotropics.

V. Holantarctic and holantarctic-neotropical-australian genera, whose habitats lie within the Australian province or else take in the north of the Australian and the south of the neotropical provinces; also genera whose habitats are only confined to the holantarctic province.¹

Within these major groups of genera, a number of subgroups may be designated whose present habitats are united by their common geographic distribution (Fig. 3). In solving the problems of floral statistics, the most reliable and precise data are supplied by plant genera, as units of a higher rank, and which are better differentiated from each other than are species. If this is true for modern flora, the taxonomy of which is immeasurably better worked out than that for the fossil flora, it is clear that going beyond generic determination to species, in the first attempt at floral analysis, would be quite hazardous, inasmuch as a specific determination by reproductive organs or by microspores is still so uncertain that gross errors in count are quite possible. Moreover, the Paleogene species are now mostly extinct.

The sequence of floras, considered as an assemblage of definite genera, should be tied in with major events of geologic history (epoch, age). In order to establish the boundaries for smaller stratigraphic elements, the migration and emergence of new genera

should be considered; therefore, it is not to be denied that the use of generic assemblages would be very helpful in detailed stratigraphic differentiation; accordingly, the determination of plant species by microspores is an important problem.

Summarizing the data of the voluminous catalogues of fossil Tertiary floras from the Aral area, Irtysh-area, and the southwestern Siberian plain, we can arrive at the following conclusions.

The extinct genera, as identified mainly by pollen and relegated to synthetic genera such as the genus *Extratropipollenites* Pfl., *Trudopollis* Pfl., also the genus *Dewalquea* and others, were developed in the Upper Cretaceous, Paleocene, and Eocene, when they also became extinct (Fig. 4).

The genera of an Indo-Malaysian-Australian distribution, especially the Australian, are best developed in Eocene deposits where their content reaches 10% to 15% of total genera.

A participation of the Indo-Malaysian-Australian genera in the flora of the Chegan series was also noted. This is especially true for the spore-pollen assemblages of its lower beds. This last circumstance may be a proof for an Eocene origin of the Chegan series.

The group of genera whose habitats correspond to the present paleo- and neotropical botanic-geographic provinces, are especially widespread in the Paleogene floras. In the Eocene deposits, especially in the upper Eocene floras (Saksaul series of A.L. Yan-shin), the number of this group is seldom less than 35% of total genera representing the upper Eocene flora.

Generally speaking, this generic group - vast, diversified, and presently associated with the subtropics and tropics - ceased to be of any importance at the upper-middle Oligocene boundary. The higher Paleogene and Neogene beds are marked only by solitary pollen findings for the species of the family Palmae, the genus *Myrtus* and others, apparently of relict origin.

The Mediterranean elements are poorly expressed in the Cenozoic Kazakhstan floras, and the presence in assemblages, and in imprints, of such genera as *Cedrus*, *Laurus*, etc., is barely noticeable at the base of the Paleogene. Toward the middle of the Oligocene, the importance of the Mediterranean component is practically nil; it is fully lacking in the Neogene, with the exception of the Aral area spectra from the Kuzha-Say locality, where the presence of genus *Cedrus* was noted, contrary to all expectations. This is

¹Systematic catalogues of floras are found in the author's report for 1957, which is the basis for the present paper.

holarctic and widespread

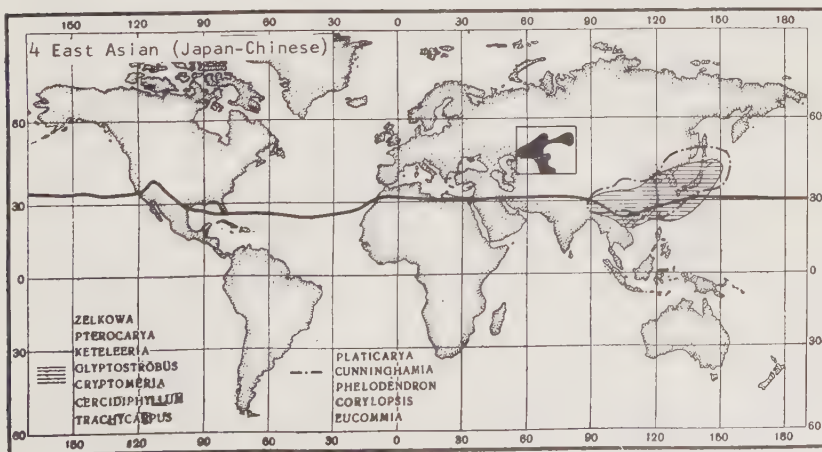
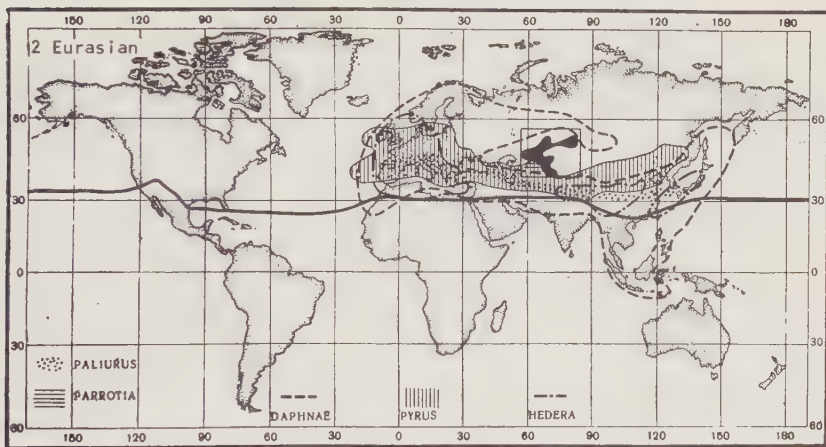
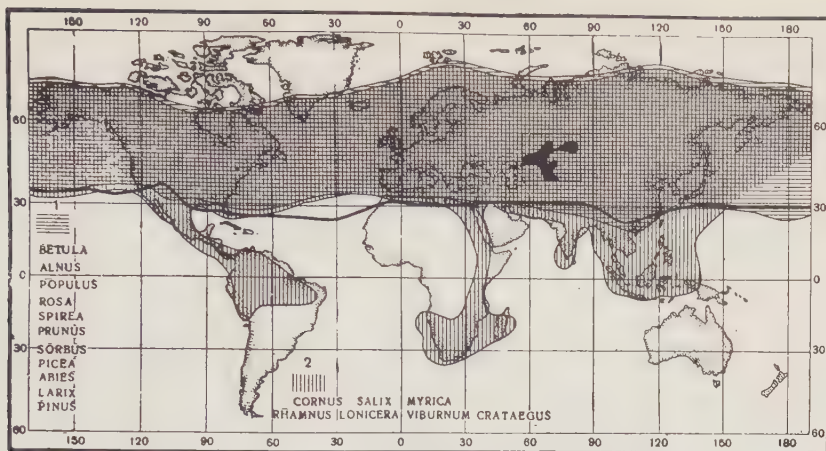
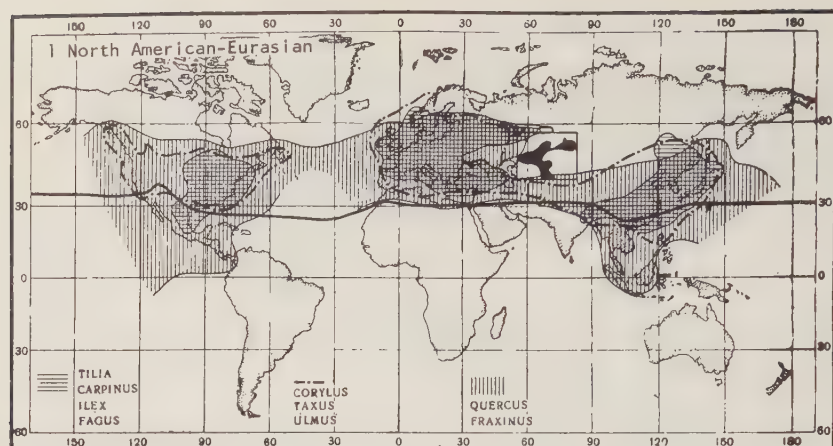


FIGURE 3. Groups of genera with common modern geographic distribution

1 -- boundaries of floral provinces; 2 -- area of paleoflora study

Holarctic



○ 1 □ 2

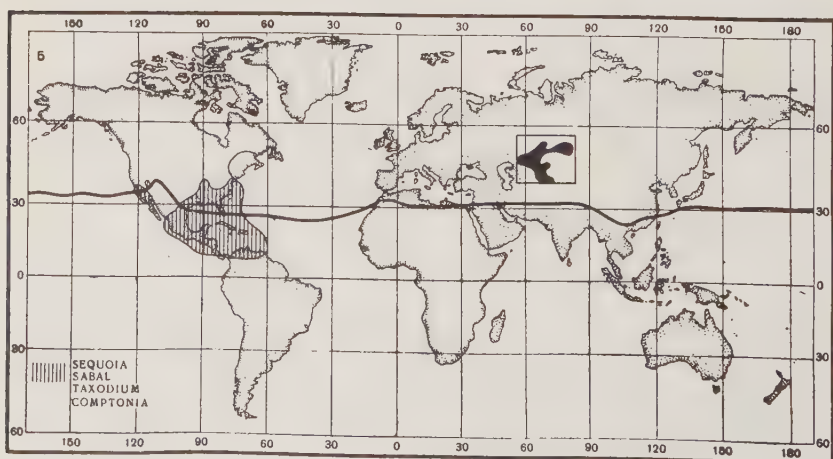
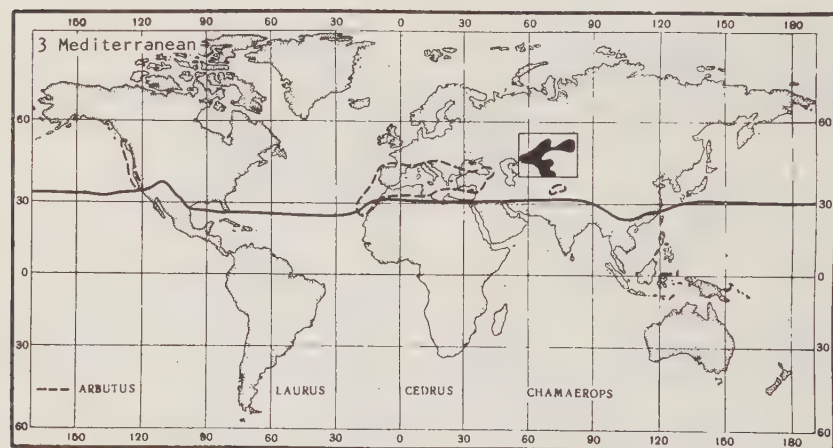


FIGURE 3, cont. Groups of genera with common modern geographic distribution
1 -- boundaries of floral provinces; 2 -- area of paleoflora study

Holarctic-paleo-neotropic (confined chiefly to south boundaries of holarctic floral province)

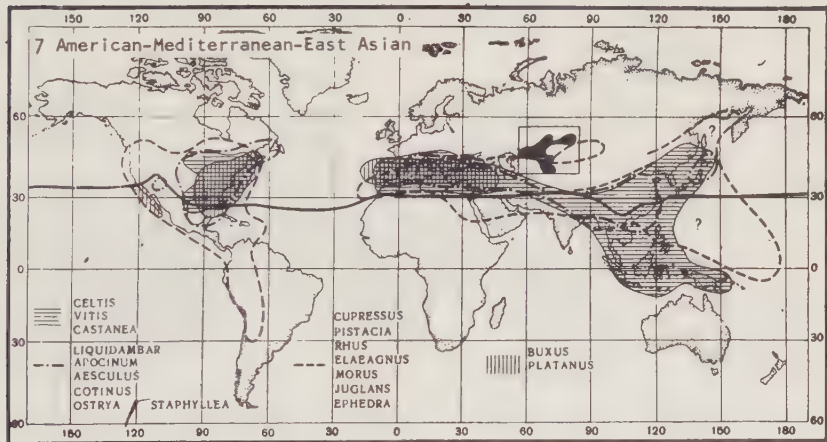
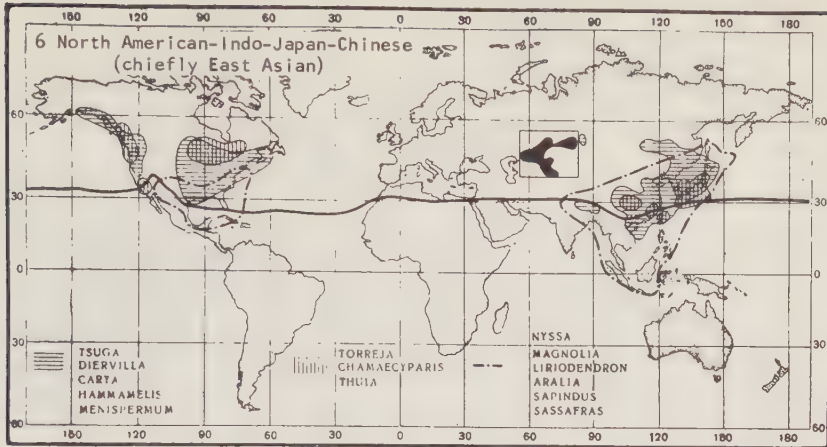


FIGURE 3, cont. Groups of genera with common modern geographic distribution

1 -- boundaries of floral provinces; 2 -- area of paleoflora study

Paleo-Neotropic-Australian and Holantarctic

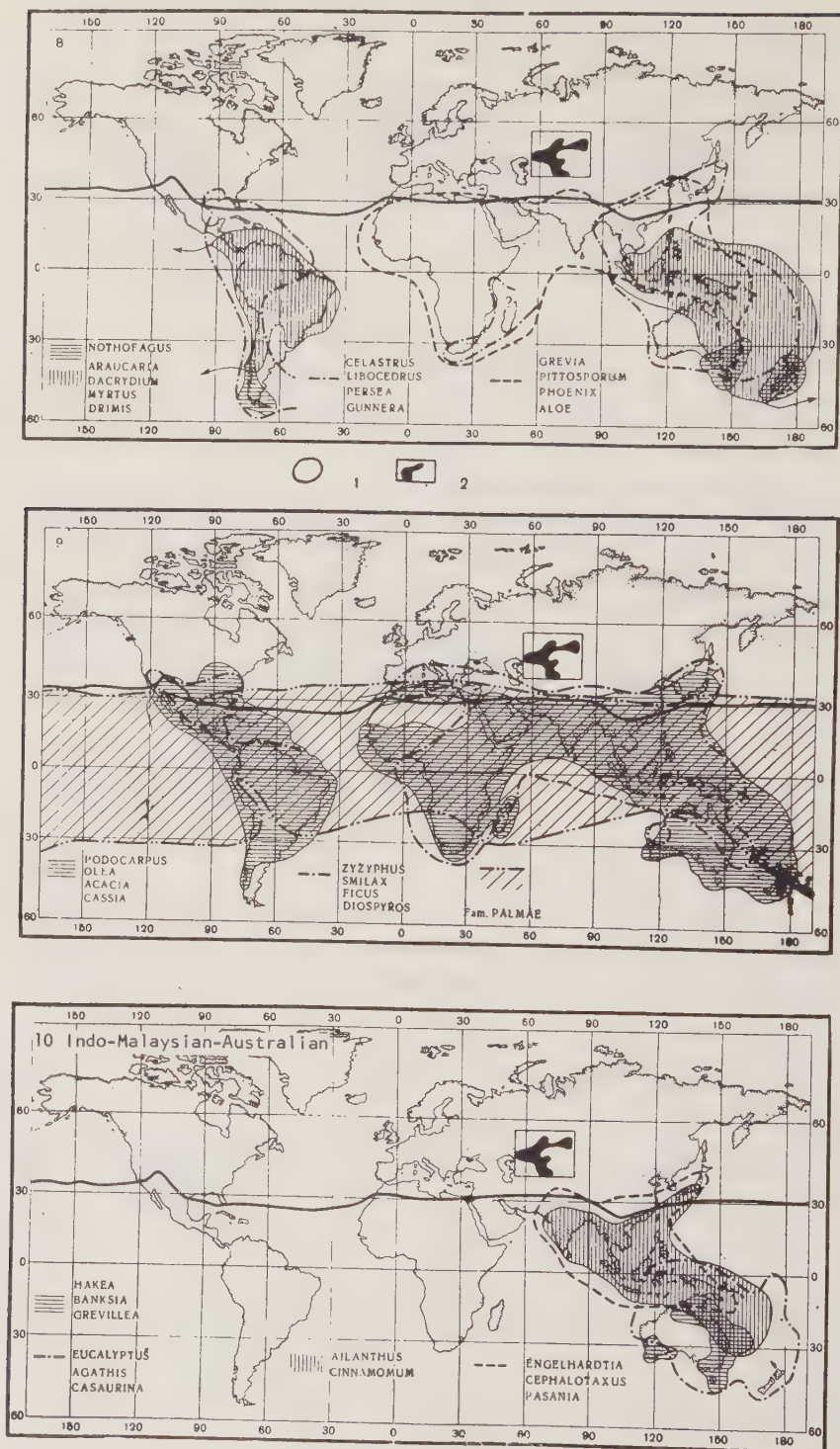


FIGURE 3, cont. Groups of genera with common modern geographic distribution
1 -- boundaries of floral provinces; 2 -- area of paleoflora study

IV Map of floral provinces (after M.V. Kul'tiyasov, 1955)

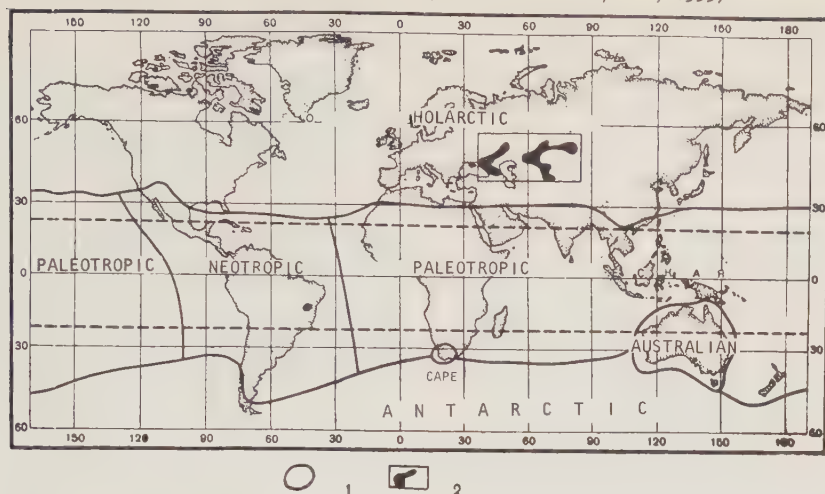


FIGURE 3, cont. Groups of genera with common modern geographic distribution

1 -- boundaries of floral provinces; 2 -- area of paleoflora study

one of the reasons for regarding the Kuzha-Say flora as belonging to the top of the Paleogene.

A group of North American genera, whose numbers are insignificant, is most widely developed in the Oligocene, Miocene, and particularly in Pliocene deposits. The number of holarctic east Asian and Japanese-Chinese genera reaches its maximum in middle Oligocene floras of the Chagray and Aral series; they are also fairly well developed in the Pliocene. The curve for a group of holarctic North American-Eurasian genera rises in steps, during all of the Cenozoic. Toward the Pliocene and Quaternary, the North American genera become predominant and in fact form a peculiar "background" in the Cenozoic flora of the southern Trans-Uralian plains.

In the Upper Cretaceous, this genera group is represented essentially by the genus *Pinus*; in Paleocene-Eocene, by the genera *Pinus*, *Picea*, *Alnus*, *Myrica*, *Salix*; in the Oligocene by the genera *Pinus*, *Picea*, *Abies*, *Salix*, *Rhamnus*, *Betula*, *Alnus*; the genera *Pinus*, *Picea* predominate in the lower Oligocene; the population of the genera *Alnus*, *Betula*, *Pinus* increases sharply in the middle Oligocene and lower Miocene, the latter genera are still represented by diversified species. In the Pliocene and Quaternary, the genus *Pinus* is best developed, with *Betula* represented by considerably fewer species, and with wide development of a genera group belonging to families Chenopodiaceae, Cruciferae, Umbelliferae, Gramineae, Potamogetonaceae, Sparganiaceae, Rosaceae.

Thus, two floras (in a broad sense) may be designated for the entire Cenozoic of the north Aral area, Turgay, Pavlodar Irtysh area, and the southern West Siberian plain: 1) subtropical and tropical, represented by a great number of genera presently having a paleo-neotropical, Australian, and holantarctic distribution (Helliden Paleocene and Poltava Eocene floras of A.N. Krishtofovich); 2) temperate flora, essentially represented by genera now distributed in the northern hemisphere (Arctotertiary "Turgay" flora as understood by A.N. Krishtofovich).

The time of the final disappearance of subtropical flora, from Kazakhstan and the southern West Siberian plain - a major stage in the development of the entire geologic setup of those regions - falls on the Eocene-Oligocene boundary. From then on, the floras lack the (now) extinct genera and the stage belongs to ascending holarctic genera now living in deciduous forests.

From the Oligocene on, the participation of holarctic flora elements, in its broad sense (I.E., including those genera whose habitats are confined to the present boundary of holarctic and paleo- and neotropical provinces) grows steadily. Conversely, the significance of the paleoneotropical elements decreases considerably.

The Kazakhstan and West Siberian Tertiary flora appears to be of an even earlier age - Upper Cretaceous; despite some participation of the now holarctic and widespread genera, it is characterized by an abundance of now extinct genera, an absolute

preponderance of the paleo- and neotropical elements, and an almost total lack of Australian-Malaysian genera.¹

In the development of the Kazakhstan and West Siberian Cenozoic flora, the following major stages may be designated, which in turn may be subdivided into stages and phases

First stage: a Paleocene-Eocene flora with considerable number of genera now extinct (Australian-Malaysian paleo-neotropical and holarctic, gravitating toward the subtropical latitudes of America and Asia). Associated with this stage are leaves and pollen of *Palmae*, *Myrtus*, and *Eucalyptus* - a representative of the family Euphorbiaceae.

The first stage may be subdivided into three phases:

1) a predominance of the Australian-Malaysian element with species of *Myrica*-like plants; Paleocene-Eocene;

2) Tropical forest phase, possibly jungle type; Middle Eocene;

3) Isolated forest phase, and savannah type vegetation; upper Eocene.

The last phase is characterized by the development of the genera *Olea*, *Acacia*, *Sterculia*, the family Euphorbiaceae, the genera *Myrtus*, *Aloe*, *Ephedra*, genera of the family Chenopodiaceae, Gramineae, Umbelliferae, Leguminosae, and by a number of genera now extinct; this is the line beyond which the now extinct genera do not persist.

Second stage: lower-middle Oligocene flora characterized by a gradual and regular increase in holarctic element, a decrease in the subtropical, and by a full degradation of the Australian-Malaysian element. This stage is subdivided into:

1) transitional phase; the Chagan series flora; upper Eocene-lower Oligocene; at the outset of this phase, its flora is so rich in subtropical elements that it can be fully relegated to the "Poltava" type, as understood by A.N. Krishtovich; as a whole, the flora of this phase is represented by forest type vegetation with some admixture of deciduous elements;

2) phase with flora of the middle Oligocene Kutanbulak and Chiliktin series.

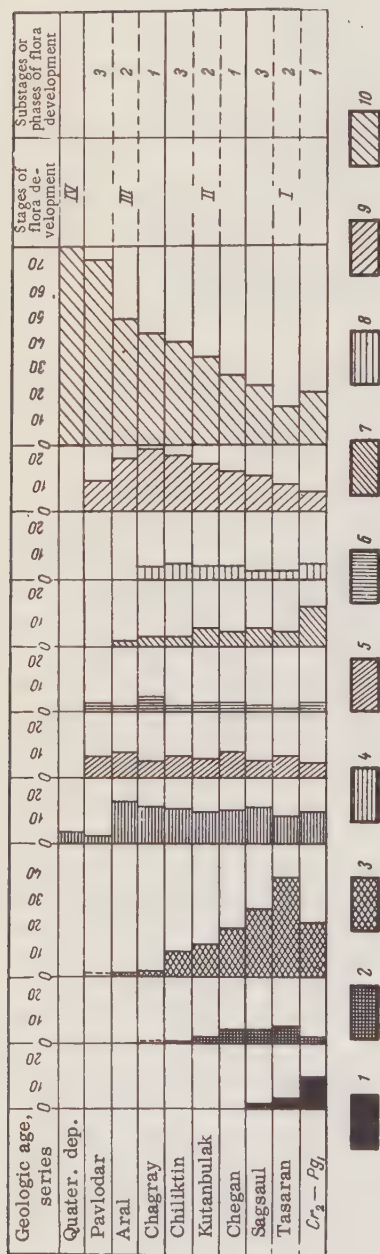


FIGURE 4. Relationships of genera groups in floras of different series.

1 -- extinct genera; 2 -- Indo-Malaysian-Australian; 3 -- paleo-neotropical-Australian; 4 -- holarctic-paleo-neotropical; 5 -- North American-East Asian; 6 -- North American; 7 -- Mediterranean; 8 -- East Asian; 9 -- North American-Eurasian (chiefly East Asian); 10 -- holarctic and widespread.

¹Cretaceous and Tertiary floras of Europe contain elements of Australian flora, up to the Oligocene.

The second phase should be considered the second stage proper in the development of Cenozoic flora. The vegetation of the second phase in the development of the second-stage flora is represented by lush broadleaf, mixed coniferous-broadleaf, and coniferous forests. The species comprising forest assemblages belong chiefly to holarctic genera whose present habitats are confined to Eurasian and North American-Eurasian centers. Yet, the admixture of those species whose genera are confined to paleo- and neotropics, is still considerable. This is a typical Turgay, Eocene-Tertiary flora, according to A.N. Krishnovich. The second phase of the second stage coincides with the spreading of the *Indricotherium* fauna.

V.S. Kornilova [16] designates our flora of the second stage as "Turgay flora" proper.

The time of the second floral development phase is characterized by a period of comparative tectonic quiet and of slowing down of erosional processes. This is the time when lacustrine-marshy basins spread over vast expanses of the southern Trans-Uralian plains, with surrounding lush vegetation.

V.V. Lavrov [19] designates the second floral phase of our outline as the *Indricotherium* stage. This is the time of a particularly great penetration of American-Eurasian genera and of a considerable increase in the number of new species of the genera *Alnus*, *Betula*, *Pinus*, *Pterocarya*, *Juglans*, and *Taxodium*. Lowland forests are widely developed. The second phase may be divided into two subphases:

1) flora with a considerable number of subtropical xerophytes (Shintuzsay assemblage of V.S. Kornilova) and

2) flora with an insignificant number of subtropical xerophytes, or altogether lacking in them (Bolattam assemblage of V.S. Kornilova.)

A third stage (Upper Oligocene-Pliocene) of the flora development emerges with a revival of tectonic activity along the boundaries of the Kazakh highlands and in the Mugodzhary. The erosive action of the river is intensified. The average annual temperatures are lower. The genera, now confined to the Australian-Malaysian centers, no longer inhabit the Aral area, Turgay, and the Irtysh area, now also virtually deserted by the subtropical Paleo- and Neotropical genera. The vegetation acquires a typically holarctic temperate aspect, with its forest assemblage dominated by deciduous species with some evergreen elements - a few species of pine and spruce.

The flora, as a whole, is dominated by the holarctic element represented by genera whose present habitats have an American-Pontian-East Asian distribution. Cosmopolitan genera are widespread. Almost lacking are the Mediterranean and North American genera, with elements of a steppe and semidesert landscape in the ascendancy.

At the boundary between the second and third stages in the flora development, there appear new mammal genera, among them *Aceratherium*, *Brachipoterium*, and later on, *Mastodon*, *Anchitherium*, and others, whose genera are adapted to an open landscape rather than to a woody terrain.

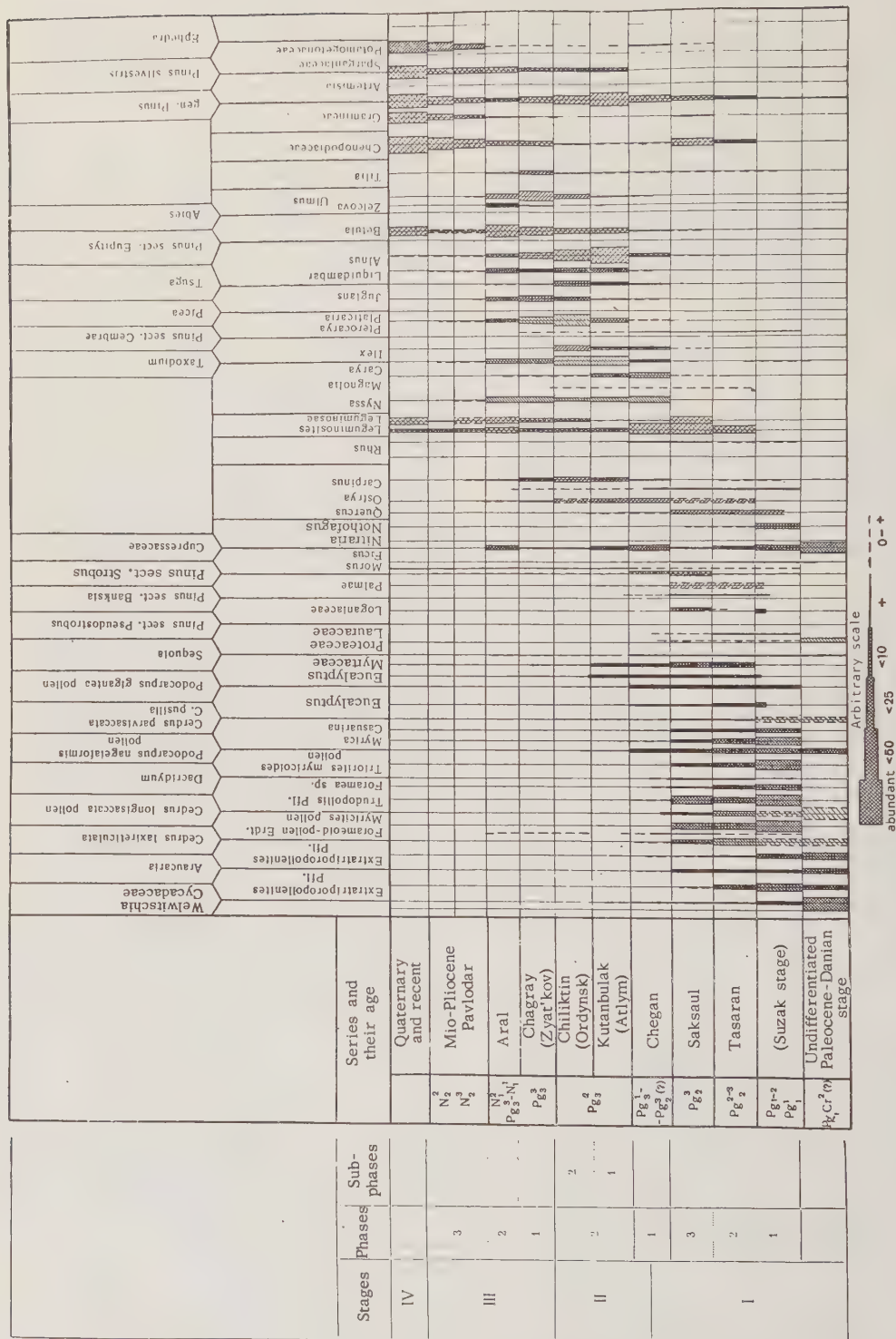
However, the character of the vegetation at the onset of the third stage remained essentially forest. Forest assemblages are represented by a mixed complex of coniferous and broadleaf species, and approach the East China type.

The gradual decrease of the annual temperatures and an intensification of the continental aspect of the climate, encourage a wide development of an open landscape vegetation type.

The third stage in the development of vegetation is marked by a gradual dying out of forest assemblages, which culminates toward its close in the formation of nearly wholly open landscapes; this coincides with the deposition of typical beds of the Aral series (greenish-gray soapy clays with manganese nodules), usually carrying large amounts of grass pollen.

This stage terminates with a definite elimination of the Mediterranean, East Asian, and subtropical elements of the flora, with a gradual dying out of the majority of the North American-East Asian genera with *Pinus*, *Picea*, *Tsuga*, *Taxodium*, and with a definite conquest of the terrain, by the North American-Eurasian elements. This stage coincides with the development of hipparions, ostriches, antelopes, and giraffes (Pavlodar fauna of the Irtysh area).

Thus, the third stage of the Cenozoic flora development may be subdivided into three phases, with the first embracing the time of deposition of the Chagray and uppermost Aral series (phase of island and band forests); the second, embracing the time of development of fresh and brackish lacustrine basins of the upper Aral beds (phase of open and mixed landscapes with remnants of island forest assemblages); finally, the third - corresponding to the deposition of Miocene-Pliocene fluvial-lacustrine sediments with a *Hipparion* fauna (open landscape phase). In correlating our data with the classification of



V.S. Kornilova [16], the flora of our first and second phases of the third stage of flora of Turgay which represents the moribund "Turgay" flora.

The time of the development and the spreading of this impoverished and essentially temperate flora, as quite correctly noted by V.S. Kornilova, endures till the end of the Tertiary, with a gradual loss of most of the archaic forms, replaced by new species, related to the present.

Unfortunately, the Late Pliocene floral complex is little known, making the sequence to the Quaternary difficult to reconstruct. Nevertheless, the data extant on the Quaternary flora make it possible to separate a fourth, and last, stage of the floral development.

This stage is featured by a total disappearance of the tropical floral element. As a whole, its vegetation is represented only by two groups of genera, whose present habitats are fully holarctic, within the Eurasian habitats; only a small assemblage of genera belongs to the American-Mediterranean-Pontian-East Asian group, related to the development of steppe and semidesert plants.

The vegetation cover of the fourth stage is familiar to use from the present aspect of the regions of our investigations: this is a province of grasses, steppe, and desert assemblages with crabgrasses, cereals, wormwood, umbellates, etc.

The arrival of forest assemblages into the early Quaternary flora, is noted at the onset of the fourth stage. As a whole, the flora of this stage is closely related to the present.

SUMMARY

Thus, as a result of a floral analysis of the data on fossil spores, pollen, and leaf imprints, it is possible to identify stages in the development of the vegetable cover, whose boundaries are of stratigraphical significance, as are the phase boundaries within these stages; this is because they are associated with stages and phases of relief formation, erosion, climatic change, and the history of faunal development (Fig. 5).

The floral analysis of data by spores, pollen, and plant imprints, makes it possible to trace the boundaries between the stages and phases of the vegetable-cover development, without any reference to a correlation of the flora findings with genetically different types of sediments. Our

working data are related to major taxonomic units (the geographic element of flora, as determined by a complex of genera, comprises an assemblage of groups of ecologically different species). The stage and phase boundaries of vegetation development, in those cases when they mark the periods of marine deposition, coincide with the boundaries as traced by fauna.

The stage and phase boundaries, as traced by the continental-deposit floras, somewhat predate those traced by the mammal fauna. This is natural, since the landscape changes are not immediately reflected in fauna changes which require time for adaption to new conditions.

This is the situation at the boundary between the second and third stages, coinciding with the Late and Middle Oligocene boundary, whereas the faunal data place this boundary between the Late Oligocene and Early Miocene.

However, in tracing the stratigraphic boundaries and in designating the stages, beds, and series on maps, the entire complex of lithologic, faunal, and floral data must be taken into consideration, even if this should lead to compromises, since a coincidence of the boundaries as determined by any of these methods, is impossible. This purpose would be served by monographs describing the fossil plant remains, down to their genera. This will make it possible to identify groups of genera within the separate phases which have a small vertical and a wide lateral distribution.

We attempted to separate such genera groups, by angiosperm pollen, but their monographic description has not, as yet, been accomplished. In any event, it can be stated that the appearance of angiosperm species related to present forms, is characteristic for the third stage in the flora development, i.e., is associated with the formation of the lower Aral beds, and with the top of the Chagray series.

In the third phase of the third stage, nearly all of the angiosperm species are related to the present.

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KARNIC DEPOSITS OF NORTHEASTERN U.S.S.R., AND THEIR LOWER BOUNDARY

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This paper gives a brief regional description of type Karnic sections of northeastern U.S.S.R., with their subdivision into two groups. The stratigraphic significance of various groups of fossil animals is considered, as well as their correlation with Karnic faunas of the Eastern Alps, North America, Indonesia, and other areas. On the basis of these studies, the author revises the former Ladinic-Karnic boundary and proposes to draw it higher on the top of the Nathorstites beds.

* * * * *

The deposits of the Karnic stage are widespread throughout northeast Asia. The west boundary of marine deposits of this stage is formed by the Verkhoysk ridge and the Nordvik-Khatanga region with eastern Taymyr; their east boundary is the Penzhina River and the western Chukhotsk Peninsula

The presence of Karnic deposits within the subject area was first mentioned by Wittenburg [16]. He concludes, on the basis of the paleontologic material by E. Toll and A. Bunge, from the Dulgoly River (left tributary of Yana, 50 km above Verkhoysk), that two Upper Triassic stages are developed in the vicinity of Verkhoysk: the Karnic, with representatives of the group Halobia falla Kittl, and the Noric, with Pseudomonotis ochotica Keys.

Almost simultaneously, C. Diener [7] found a large number of Karnic forms in the fauna collected by E. Toll along the Balykty River, Koteln'nyy Island (New Siberian Archipelago).

In 1917, P. A. Kazanskiy [2] established the presence of Upper Triassic along the Okhotsk Sea shore, between Okhotsk and Yamsk. As identified by A. A. Borisyak, the fossils collected date the deposits as Noric and Karnic.

Considerably later, M. V. Bayarunas [1] and L. D. Kiparisova identified numerous Karnic pelecypods and ammonites in the rich collections of S. V. Obruchev (1926, 1929-1930) combined with an old collection by I. D. Cherskiy (1891).

From 1933 on, the systematic and well-planned efforts by a large group of geologists of the Dal'stroy have established an extremely wide distribution of Upper Tri-

assic deposits, including the Karnic stage, over the entire vast territory of the northeastern [Soviet] Union.

The Karnic stage conformably overlies the Middle Triassic, commonly with a gradual change of Middle Triassic Ladinic deposits into the Karnic.

CHARACTER OF DEPOSITS

The most complete Karnic sections, carrying a rich fauna, are observed within the Yana-Kolyma geosyncline.

In the upper reaches of the Kolyma River (Kulu, Sinike, Detrin Rivers), and in the adjoining Yana (Okhotsk) area, these deposits are divided into two groups.

The lower part of the Karnic stage is made up, at its base, almost exclusively by shales and sandy shales, with rare intercalations of fine-grained, locally cross-bedded clayey and polymineral sandstones. Higher up, pyritic sandy shales predominate.

Still higher up, the amount of sand increases, with sandstones and sandy shales in local development. Pyritization is strong, with pyrite usually forming irregular bodies with inclusion of small crystals. On decomposition, the pyrite changes to iron hydroxides in minute incrustations, spots, flow lines, and medallions, coloring the rock brown-red. Common are hard spheroid and ellipsoid concretions of various dimensions, usually containing a well-preserved fauna. They consist of clay-siliceous material, with some lime and locally iron, because of which some of their fossils are pyritized.

The lower part is characterized by the following forms: Clionites aff. spinosa Mojsisovics, Cl. aff. compressus Hyatt and Smith, Cl. cf. spiniger Popow, Sirenites enticosus Dittmar, S. aff. vestalinae Mojs., S. hayesi Smith, S. jakutensis Kiparisova, S. irregularis Kipar., S. bilibini Kipar., S. Kalugini Kipar., Acanthinites cf. calypso Mojs., Mojsvaroceras cf. turneri Hyatt and Smith, Arcestes (Proarcestes) cf. gaytani Klipstein, Halobia superba Mojs., H. zitteli Lindstrom, H. obruchevi Kipar., H. cardinifera Smith, Lima subpunctata d'Orbigny, Pecten aff. subalterni costatus Bittner, Necula trigillata Goldfus, Palaeoneilo lunaris Bohm.

The upper group of the Karnic stage is represented by sandy shales locally carrying much marcasite and pyrite. It is characterized by a rich pelecypod fauna with Rhynchonella aff. sumrimkiensis Krumbek, Pecten sibhiemalis Kipar, Oxytoma mojsisovičsi Tell., Halobia zitteli Lindst., H. kolymensis Kipar, Cardinia ovula Kittl, Myophoria olitaria Bittn. in association with such rarer forms as Monotis scutiformis var. typica Kipar., M. daonellaeformis (Kipar.), Palaeoneilo lunaris Böhms.

The greatest thickness of the Karnic deposits for the Upper Kolyma area is from 900 to 1500 m; less common are thicknesses of 50 to 600 m, associated with limbs of antinormal uplifts.

To the northwest, in the area of the upper Indigirka River, with its continuous Upper Triassic belt trending from the southeast, the Karnic stage, rich in fauna, is represented by the same arenaceous-argillaceous series, conformable over the Middle Triassic, as it is in the upper Kolyma area. Here it differs somewhat because of the appearance in its upper portion, of arkosic and graywacke sandstones, somewhat limy. The thickness of the deposits generally varies from 1,000 to 1,500 m, and does not exceed 2,000 m.

Cephalopods likewise are distributed here in a lower layer where they are most abundant and diversified (Arcestes, Clionites, Sirenites, Anasirenites; specific names are the same as in the previous section); there are numerous pelecypods, especially diversified in an upper layer of the Karnic stage (Halobia, Myophoria, Leda, Necula, Anadonophora, Cardinia, Pecten, M. scutiformis).

The Karnic deposits are somewhat different in the Kyuyent-Suantar-Bryungadin inter-river area. Here they contain fine-grained sandstones, fairly thick, interbedded with light-gray coarse to medium-grained sandstones with lentils and lenses of fine-gravel conglomerates carrying rich plant detritus.

Along the northeastern limb of the Yana-Kolyma geosyncline, in the southwestern and northwestern chains of the Chersk and in part the Polousnyy ridges, the Karnic section is less complete and somewhat different in its composition, being richer in lime and containing thin lenses and beds of dark-gray limestones.

The lower group of the Yana Karnic stage is made up chiefly of greenish-gray, thin-bedded, pyritic shales and sandy shales. In places, fine-grained sandstones occur in thin beds among the shales. Clay-siliceous concretions are very common and numerous and also lenses and intercalations of biogenic bituminous limestones. Identified from concretions and shales are: Sirenites hayesi Smith, S. aff. kohanyi Mojs., S. aff. irregularis Kipar., Clionites (Dawsonites) canadensis Whiteaves, Pinacoceras cf. regiforme Diener, Arcestes (Proarcestes) cf. gaytani Klipst., A. (Proarcestes) verchojanicus Kipar., Daonella aff. frami Kittl, Halobia cordillerana Smith, H. austriaca Mojs., H. zitteli Lindst., H. superba Mojs., H. obruchevi Kipar., H. kolymensis Kipar., H. suessi Mojs., Gryphaea cf. arcuataeformis Kipar., G. cf. keilhau Bohm, Oxytoma, Pecten, Rhynchonella sp.

The amount of sand gradually increases in the upper Karnic group, along with the appearance of some lime in the medium-grained siltstones interbedded with less common shales and sandy shale, locally calcareous. Common among the sandstones are thin lenses and beds of gray sandy limestones with scattered fine pebbles of quartz, black slate, and jasper rock. The following fossils are index for the upper group: Monotis zitteli Tell., M. scutiformis var. typica Kipar., Halobia zitteli Lindst., H. cf. suessi Mojs., Pecten cf. sibhiemalis Kipar., P. suzukii Kobayashi, Oxytoma mojsisovičsi Tell., Cardinia cf. ovula Kittl, Spiriferina sp.

The majority of these forms (Spiriferina, Oxytoma, Pseudomonotis, Pecten), as in the previous, Kolyma, section, appear for the first time in the upper Karnic group, alongside the forms continuing from deeper layers (Halobia, Cardinia). Most of them, however, pass on into the overlying Upper Triassic formations. The thickness of the Karnic here is 600 to 1,800 m.

North shore of the Sea of Okhotsk. Going east and southeast, into the Okhotsk geanticline area, the Karnic deposits wedge out, partially or entirely. The small disconnected areas of Karnic deposits, exposed by erosion below the thick Cretaceous volcanics are represented by shales and sandy shales with pyrite and marcasite concretions, and by sandstones locally containing layers of inter-

formational conglomerates and limestones. The usual bivalve fauna occurs mostly in the upper part of the Karnic stage. The thickest Karnic deposits here attain 600 to 700 m, thinning in isolated localities, generally as little as 250 to 300 m, but in places even to 100 m. Such thickness variations reflect the corresponding variations of the Karnic section. Thus, along the Okhotsk shore, various Karnic layers are in contact with the upper Paleozoic; locally they are entirely missing. Along the entire west slope of the Verkhoyansk ridge, the Karnic stage appears to be represented by sandy-conglomeratic continental sediments comprising an interval between the Lower Triassic and Liassic marine deposits.

Middle course of the Kolyma River. The Karnic here is represented by thick arenargillaceous formations carrying numerous pyrite and marcasite concretions with radial-ray structure. The rocks are dark-gray to black thin-bedded shales and sandy shales interbedded with gray and greenish-gray cross-bedded siltstones and sandstones, slightly calcareous. Layers of alternating shales, siltstones, and sandstones, as much as 10 to 20 m thick, are observed. The coarser varieties, sandy shales, less commonly fine-grained shaly sandstones, slightly sericitized, occur chiefly in the upper part; with the shaly beds, in the lower. Spheroid and ellipsoid concretions are common. The thickness of these deposits varies from 300 to 1,200 m.

The lower shale formation of the Karnic stage with a cephalopod and pelecypod fauna of northeastern Siberia, is well known and widespread.

An upper formation of sandy shales with interbeddings of sandstones, shales and lentils of shell limestone with Monotis moutiformis var. typica Kipar., Oxytoma, and rare Halobia, is correlative with a corresponding formation from the Trans-Baikal and the Ussuri region.

East Kolyma regions. The lower Karnic group includes an essentially shale series, consisting at the base, of thin-bedded sandy shales interbedded with thin siltstones and dark limestones, locally fringed by a cone-in-cone structure. In weathering, the argillaceous beds range in thickness from several centimeters to tens of meters, are irregularly fissile and are commonly split into small angular fragments. The shales are dark-gray to black, with a greenish to brownish tint, depending on the amount of chlorite, carbonaceous matter, and hydrous ferric oxide. The shales are intensively pyritized, with the pyrite occurring either in fine individual crystals or in rounded

concretions. Higher up, the shales carry layers and lenses of tough dark-gray, thin-bedded siltstones, more uniform toward the top.

Going upward, there is a gradual increase in sand content and a transition to the following series of nearly massive dark-brown-gray sandy shales with worm-like inclusions of clay-carbonaceous material; the rocks become slightly calcareous, locally tuffaceous. Commonly, the shales are in a lenticular alternation with dark-brown sandstones. Shales with slaty partings are rare, usually breaking into small, flat fragments, or else into coarse, often beveled, prisms. Accumulations of micaceous material are observed in partings and bedding planes, which is typical for the entire Karnic section. To the north, in the area of the Balygychan and Sugoy Rivers, these shales are interbedded with more numerous fine-grained arkosic and tuffaceous sandstones. Still farther north, on the left bank of the Kolyma, argillaceous limestones are in the ascendancy among the sandy and limy shales. Rare lentils and lenses of dark-gray marly limestones among the Karnic shales are also present to the northeast, in the headwaters of the Omolon and Gizhiga.

Very characteristic is the constant presence of hard spheroid and ellipsoid clay-siliceous concretions, calcareous, commonly carrying a rich cephalopod and pelecypod fauna: Sirenites aff. hayesi Smith, S. cf. stratofalcatus Hauer, Halobia austriaca Mojs., H. superba Mojs. var. timorensis Krumb., H. zitteli Lindst., H. cordillerana Smith, Palaeoneilo lunaris Böhm, Nucula strigillata Goldf., Lima (Plagiostoma) cf. spitzbergensis Lundgren and some other pelecypods, brachiopods, and gastropods.

In the upper Karnic group, the sandy shales become less uniform, are cross-bedded with numerous lenses and concretions of sandy limestones and calcareous sandstones. A very rich fauna of brachiopods and pelecypods: Spiriferina aff. pittensis Smith, Omolonella cf. omolonensis Mojs., Terebratula sp., Oxytoma cf. mojsisovičsi Tell., Gryphaea keilhau Böhm, Cardinia ovula Kittl, Lima (Plagiostoma) ussuriensis Voronec, L. (Plagiostoma) cf. subpunctata d'Orb., Pleurophorus suifunensis Kipar., Anodontophora sp., Halobia sp. indet. The overlying black shales with Halobia indigirensis Popov, H. cf. kolymensis Kipar., Luma (Plagiostoma) ussuriensis Vor. and rare Monotis scutiformis Tell. are correlative with the uppermost Karnic beds of Soviet Asia.

The overall thickness of the Karnic stage ranges from 350 to 1,000 m. Its thinning to several hundred meters is observed also to the northeast, in the direction of the Omolon

and Korkodon headwaters. Karnic deposits, very similar to these, are developed in the Rassokha (Korkodon) and Berezovka River basins.

Central massifs of the geosynclinal province. Of a somewhat different character are these deposits in the confines of the Indigirka-Kolyma (Paleozoic chains of the Chersk ridge) and Omolon-Korkodon central massifs. Here their sections are thin and contracted. In the Omolon-Korkodon massif area, the Karnic is represented only by its upper part. Its small exposures are observed along the lower Korkodon course, along the Nyanika, Russkaya, Malaya Ammandzha Rivers, also the Astronomicheskaya River (source of the Kedon River) and at the mouth of the Finish River (lower course of the Kedon River); at the base of the section, there lie brown-gray, locally calcareous sandstones with rare intercalations of silty shales carrying *Rhynchonella* ex gr. *superba* Bittn., *Spiriferina* sp., *Entolium* cf. *obergi* Lundg., *Pecten* cf. *deformis* var. *polaris* Wittenburg, *Lima* (*Plagiostoma*) cf. *spitzbergensis* Lundg., *Halobia* sp., ammonites with ceratite sutures, possibly *Sirenites*.

Higher up, there lie calcareous, detritic, greenish-brown polymineral sandstones and layers, 0.1 to 0.2 m thick, of slightly cherty, slaty, thin-bedded sandy shales and shales saturated with bitumen. Very common in the upper part of this group are lentils of light-gray fine-grained calcareous siltstones and dark-gray brittle sandy shales. Gravel conglomerates occur in layers among the sandstones (Russkaya River), whereas the shales carry small pyrite concretions, unidentifiable flora imprints, and intercalations of black, glossy coal. Going up, the fauna remains become more diversified, being represented by *Monotis scutiformis* var. *kolymica* Kipar., *Oxytoma zitteli* Tell., *O. mojsisovičsi* Tell., *O. czezanowskii* Tell., *Halobia obruchewi* Kipar., *H.* cf. *fallax* Mojs., *Pecten* cf. *laevigatus* Schlotheim, *Gryphaea arcuataeformis* Kipar., *Zeilleria kolymensis* Moiseev and other, unidentifiable gastropods, brachiopods, cephalopods, and animal bone fragments.

The thickness of the deposits generally ranges from several tens to 70 m, but apparently never exceeding 100 m. These deposits rest directly upon the Permian.

Within the Indigirka-Kolyma massif (Paleozoic chains of the Chersk ridge), only small islands of Triassic deposits have been left by erosion. The Lower and Middle Triassic deposits are nearly absent; in individual localities of the massif (top of Mt. Zyr-yanka), Ladinic beds rest unconformably upon various Paleozoic series. In the major-

ity of cases, the Triassic section opens with an incomplete Karnic stage. Even that is commonly missing, so that the Paleozoic deposits are overlain unconformably by the Noric. It follows that good full Upper Triassic sections are not to be looked for here, as they are not in the Omolon-Korkodon massif. In the light of the new data by A.A. Nikolayev (oral communication), who has described here a nearly full Karnic section, its lower group should include, besides the 20 to 50 meters of barren tuffs and tuffaceous sandstones interbedded with tuff-conglomerates, the calcareous tuffs, and limestones with calcareous shales carrying loaf-like concretions. The latter contain *Sirenites* ex gr. *stratofalcatus* Hauer, *Discophyllites* ex gr. *ebneri* Mojs., *Cosmonautilus* sp., *Scurria* ex gr. *depressa* Koken, *Halobia zitteli* Lindst., *H. suessi* Mojs. Besides these forms, there occur pelecypods, less commonly brachiopods, chiefly in higher layers -- *Monotis* sp. nov., *Oxytoma* aff. *mojsisovičsi* Tell., *Cardinia* cf. *ovula* Kittl, *Rhynchonella* sp., whose mass accumulations form shell beds.

The overlying dark-gray calcareous shales and argillaceous limestones with *Halobia zitteli* Lindst., *Monotis scutiformis* var. *typica* Kipar., *M. daonellaformis* Kipar., correspond to the upper Karnic group. The overall thickness of the Karnic here is 200 to 350 m.

On the Kotelnyy Island of the New Siberian archipelago, the dark calcareous shales with abundant concretions of bituminous, strongly pyritic marly limestone carrying *Daonella frami* Kittl, *Halobia zitteli* Lindst., *Rhynchonella wollosowitschi* Dien and more seldom ammonites *Nathorstites* cf. *lenticularis* Whit., *Placites* cf. *oldhami* Mojs., *Arcestes* (*Proarcestes*) cf. *gaytani* Klipst., *Clionites* sp. may be assigned to the lower Karnic beds. The composition of the upper Karnic beds remains unknown here.

The Karnic stage is almost unknown from the Chukotsk region, with the exception of the eastern part of the Chaun spit and the upper course of the Anyuy River. On the Kalen'mu-Vaam River, near Talya-Vaam (eastern part of the Chaun spit), as well as on the right bank of the Malyi Anyuy River and at the headwaters of the Obil'nyy River only the uppermost Karnic is present, represented by black shales and quartz sandstones with *Halobia*, *Monotis scutiformis* var. *typica* Kipar., *Gryphaea* cf. *arcuataeformis* Kipar., *Laevidentalium* sp.

The upper boundary of the Karnic stage in the northeastern U.S.S.R. is locally clearly marked by a change in the lithology. Thus, in the upper Kolyma area and east from there, it is traced at the base of the

overlying shales and pyroclastic formations, and is marked not only by the change in rocks, but by a common occurrence of shell limestones and shell beds at the base of the Noric stage. In some areas along the upper course of the Indigirka and Yana Rivers, located along the southwest limb of the geosyncline, and partially in the Upper Yana area, the upper Karnic boundary is clearly marked by a change of shales and sandy shales to sandstones with lenses of conglomerates not uncommon. In most areas, this boundary is traced by a fauna change within a monotonous expanse of sandstones and shales.

ANALYSIS OF THE FAUNA

In the process of a detailed study of the Karnic deposits from the northeastern U.S.S.R., and of their correlation with those from the Eastern Alps and, in part, North America, Indonesia, and other areas, certain controversial points of the stratigraphy of these formations were encountered, the foremost among them being the position of the lower Karnic boundary. There is a school of thought among our own and foreign geologists, maintaining that the *Nathorstites* beds of the boreal basin should be relegated to the lowermost Karnic, the *Dawsonites* zone. The latter is correlated, without much justification, with the *Trachyceras aonides* zone of Eastern Alps, thus lowering the Middle-Lower Triassic boundary.

However, according to the stratigraphic and paleontologic data, the *Nathorstites*-carrying deposits should be assigned to the upper Middle Triassic, i.e., to the Ladinic stage.

The first attempt at reviewing the age of the *Nathorstites* beds was made by Yu. N. Popov [4, 5] from the material provided by the Kolyma geologists. Popov puts the lower part of these beds in the Ladinic stage, and their upper part in the Karnic. The same opinion was shared, much later on, by L.F. Spath [14] and F.H. McLearn [11].

Passing to a more detailed consideration of the age of the *Nathorstites* beds, J. Smith puts all the *Nathorstites* of the boreal Triassic deposits of British Columbia, Alaska, and North Arctic Ocean, into the *Dawsonites* zone, with a reservation that the stratigraphic position of that zone is not clear and that its relegation to the Karnic base is conditional [13, p. 10]. Moreover, it also is not clear whether all the species included into that zone by J. Whiteaves, have come from the same layer. Turning directly to J. Whiteaves [17, p. 133], we learn that,

alongside *Nathorstites mcconnelli*, *Daonella dubia* Gabb has been found in the Lier River locality, which is an index form for the upper Middle Triassic of North America. At a much later date, McLearn's works [11, 12] point out that no form from the Karnic stage has been found in association with *Nathorstites*. On the contrary, there is evidence of Ladinic *Daonella* in the *Nathorstites* beds of the Lierd formation, in northeastern British Columbia (Lierd River). It also should be kept in mind that this formation overlies uninterrupted the Toad formation whose upper part carries an Anisic *Beyrichites*-*Gymnotoceras* fauna. It is no wonder, therefore, that F. McLearn, while referring to the *Nathorstites* deposits (Lierd formation) as Ladinic-Karnic, in a peculiar tribute to the past in his correlation chart, in his latest work [12], puts the entire Lierd formation into the Ladinic stage.

The *Nathorstites* deposits of Spitzbergen are subdivided by E. Stolley into two parts: the lower with *N. tenuis* and *N. gibbosus*; and the upper, with larger forms, *N. lindstromi*. More recently, this subdivision of the *Nathorstites* deposits was confirmed by H. Frebold. However, in a more detailed description of fauna from another Spitzbergen locality, H. Frebold points out that *Nathorstites lenticularis* W. has been found by A. Orwin in the same beds with *Ptyches* (Anisic stage ammonites; 9, pp. 17-18). This bed is but 3 m thick and H. Frebold can only assign its upper part to the Karnic, and the lower to the Anisic, thereby denying the existence of the Ladinic stage. Of course, it would have been more correct to include the *Nathorstites* beds with the Ladinic, thereby eliminating a number of inconsistencies and reservations in connection with the alleged lack of the Ladinic on Spitzbergen.

An assemblage of *Dawsonites canadensis* (Whit.), *Nathorstites lenticularis* (Whit.), and possibly *N. tenuis* Stolley, found in a lower Urds Berg shale bed at the base of *Nathorstites* beds of Bear Island, establishes the presence of *Dawsonites* zone. Also established is the overlying formation (*Miphoria* sandstone) with enlarged forms of *Nathorstites lindstromi* Bohm, *N. mojsvari* Bohm, in association with less numerous *Dawsonites canadiensis* and *Nathorstites lenticularis* (Whit.) [6]. It is extremely interesting that the lower Karnic age of the Bear Island *Nathorstites* beds has been established by I. Bohm by analogy with the Lierd formation of the more recent students (of British Columbia). Thus, the circle has been closed. However, the doubts as to the lower Karnic age of the *Nathorstites* beds have in no way been eliminated.

Turning to northeast Asia, we see Anisic deposits there being overlain by shales and

siltstones with peculiar ammonites and *Daonellas* of the Ladinic stage. The latter, in their turn, change to Karnic shales with *Sirenites* of the group *S. senticosus* Dittm. and numerous *Halobia*. In our sections, the *Nathorstites* beds were usually designated as intermediate Ladinic-Karnic, not always paleontologically substantiated to the same degree. In many places *Nathorstites* occurs in association with other fossils, unfortunately of no stratigraphic significance. This circumstance, as well as the tradition of putting all *Nathorstites* into the base of Karnic, have led to an erroneous belief held by most Kolyma geologists, including the author, on the isolated position of the *Nathorstites* beds correlative with the *Dawsonites* zone.

It was established subsequently that, with the *Nathorstites* and related to it, new genera of Ladinic ammonites (*Indigirites* and *Paraindigirites*) occur in the Okhotsk-Kolyma region, as described by Yu. N. Popov [4, 5]. Common in these deposits are ammonites related to *Parapopanoceras*, but with more intricate sutures, separated by Ye. V. Voytova into a new genus *Amphipopanoceras*. Yu. N. Popov notes that all these ammonites stem out of an Anisic genus *Parapopanoceras* which lived only in the boreal basin and in North America and is unknown in the USSR region, Japan and the Alpine-Himalaya geosyncline. In evolution, this was the genus which, in the Ladinic time, launched new endemic genera (*Paraindigirites* - *Indigirites* - *Nathorstites*) whose habitat coincides with that of *Parapopanoceras*, and is as circumscribed. Associated with these ammonites is the Ladinic *Daonella* and a new species of *Halobia*, related to *H. vixaurita* Kittl., also known to be characteristic of the Ladinic Alpine stage. The uppermost part of the series contains beds of sandstones and siltstones with spirifers related to *Spiriferina* *baikhikuana* Trechman, from the Ladinic of New Zealand [10].

While on this subject, there is another very essential detail to be considered. Some *Nathorstites* are so similar to new ammonite genera from the Ladinic of Northeast Asia, that we are not at all sure of the infallibility of the identification of various *Nathorstites* species, and in the dating of deposits on this basis. Several examples, borrowed from Yu. N. Popov's work, illustrate this point [5]. Thus, greatly enlarged inner whorls, and the general character of sutures, brings together a Ladinic species such as *Indigirites* *trugi* Popov and *Nathorstites* *lenticularis* Whit., with but insignificant differences.

In its shell form and ornamentation, *Indigirites* *tzaregradskii* Popov, as described by Yu. N. Popov, is very reminiscent of *Nathorstites* *moisvari* var. *applanata* Böhm. In its

general aspect and size, *Paraindigirites* *vas-kowskii* is very reminiscent of *Nathorstites* *mcconnelli* (Whit.) and *N. lenticularis* (Whit.), differing from them in a thinner cross section of its whorl and in less spheroidal inner whorls.

Only small sutural differences and a greater thickness of the whorls stand in the way of identification of the *Indigirka* *Paraindigirites* *planus* Popov with the Spitzbergen *Nathorstites* *tenuis* Stolley, although the kinship of the two species, according to Yu. N. Popov, is striking, and it appears that *N. tenuis* should be relegated to *P. planus*. There are any number of such instances.

All of what has been said about *Nathorstites* necessitates a review of the age of the boreal Triassic *Nathorstites* beds referred to the so-called *Dawsonites* zone in British Columbia, Alaska, and the Spitzbergen Archipelago. This seems to be in opposition to a finding of *Nathorstites* cf. *lenticularis* (Whit.) in association with typical Karnic forms, on Kotel'nyy Island. However, the *Nathorstites* came from the right bank of the Reshetnikova River, whereas the other forms came from the Balykhtakha River, i.e., from various points. Consequently, here too, there are no definite indications of *Nathorstites* age. This justifies assigning the *Nathorstites* beds to the Ladinic stage. This is also suggested by the previously mentioned paleontologic and stratigraphic data which no longer permit the *Nathorstites* beds to be designated as a separate zone at the base of the Karnic stage.

The conclusion is, that the Ladinic stage, with its well-developed endemic genera, should be ended with beds which contain *Nathorstites*, *Paraindigirites*, *Daonella*, and the peculiar *Spiriferina*. However, it does not follow that *Nathorstites*, and especially *Dawsonites*, are confined exclusively to the Ladinic stage. They may occur, and *Dawsonites* definitely does, higher up, in Karnic deposits.

The lower boundary of the Karnic stage deposits, where they rest without a break directly on the Ladinic, should be traced at the base of the beds carrying numerous typically Karnic *Halobia*, *Clionites*, and especially *Sirenites* of the *S. senticosus* group. Tectonic activity at the Middle-Upper Triassic boundary led to a wide, progressive Karnic and Noric transgression. It also established a free communication between the Boreal sea and the Pacific, which, in turn, led to mixing of faunas of different provinces. Endemic genera like *Indigirites*, *Paraindigirites*, *Nathorstites*, and *Dawsonites*, disappeared, while extensive distribution was achieved by Mediterranean and Himalayan genera - *Proarcestes*, *Protrachyceras*, *Dis-*

cophyllites, Clionites, Sirenites, Anasirenites, Pinacoceras, Placites, Sagenites, and Acanthinites.

Thus, a changed tectonic regime of the close of the Upper Triassic, which caused a broad Karnic sea transgression and a resulting rejuvenation of fauna, suggests that the problem of the upper Ladinic and lower Karnic border has been correctly solved. Two faunal groups are thus separated in the Karnic of northeast Asia.

The Lower group is thicker (500 to 1,300 m) and carries an abundant and diversified fauna, from crinoids to cephalopods. Among the crinoids, Isocrinus, is widespread and is related to Isocrinus californicus Clark, from the Karnic of North America.

Among the brachiopods, the genus Rhynchonella is represented by two species: R. wollossowitschi Dien. and R. ex gr. teobaldiana Stell. The first is most similar to Rhynchonella trinodosa Bittn. from the Himalayan lower Karnic, a form closely related to the second is known from the Timor Ladinic.

Among the pelecypods, the following genera are present: Palaeoneilo, Nuculo, Trigonodus, Daonella, Halobia, and less commonly Pecten and Gryphaea. Indicative as to the age are: Nucula strigillata Goldf., encountered near the base of the Karnic of Japan, South China, and especially the Alps; Trigonodus serianus Parona, known from a lower Karnic formation of the Alps; Anodontophora lettica Quenstedt and Myophoria laevigata Ziet., also characteristic for that zone; Myophoriopsis (Pseudocorbula) gregaria Phillips and Gonodon mellingi (Hauer), which usually occur in the lower Karnic of the Alps and Himalayas; Daonella frami Kittl, Halobia austriaca Mojs., H. amoena Mojs., H. charlyana Mojs., H. cassiana (Mojs.), H. Iommeli Wissman, H. suessi Mojs., H. zitteli Linds., H. superba Mojs., H. brooksi Smith, H. gigantea Smith, and other Halobia peculiar to the Karnic of the Mediterranean, Timor, South China, Japan, and North America; the latter occur not only in the lower Karnic but persist into higher beds. Considerably less diversified is a class of gastropods represented by local forms of two genera, Worthenia and Fedaiella.

A strong influence of the faunal elements of the American, Himalayan, and Mediterranean provinces is shown in the presence of such typically Karnic ammonites as Discophyllites cf. ebneri Mojs, known from the lower Karnic beds of Timor and Himalayas; Trachyceras (Protrachyceras) lecontei Hyatt and Smith, occurring, according to Smith's data, in various intervals of the Karnic

section and very similar to Trachyceras attila Mojs., from the Trachyceras aonoides zone; Clionites (Dawsonites) canadensis Whit., and other Clionites which, in northeast Asia, are associated exclusively with the lower part of the Karnic stage.

The genus Sirenites, very broadly represented among the ammonites of the lower horizon, comprises 12 species: S. hayesi Smith, S. irregularis Kipar., S. senticosus Dittm., S. obruvcevi Bojaranus, S. aff. vestalinae Mojs., and other Sirenites belonging to the Sirenites senticosus Ditt. group, and also Sirenites striatofalcatus Hauer and S. vestalinae Mojs.

Representative of the genus Sirenites are distributed chiefly throughout the Karnic stage. The general developed in the Karnic of the northeastern (Soviet) Union (listed above), are typical for a lower Karnic zone, the Trachyceras aonoides zone of the eastern Alps.

Pinacoceras regiforme Dien is most similar to the Alpine P. rex Mojs., from the Karnic stage. Arcestes (Proarcestes) gayatani Klipst. occurs in a lower Karnic zone of Himalayas and Eastern Alps; Monophyllites simoni (Hauer) is also associated with the lower part of the east Alpine and Himalayan Karnic. Isolated Placites are represented by a species showing a great similarity to P. oldhami Mojs., from the upper part of the Ladinic stage.

Besides the above named ammonites, the lower part of the Okhotsk-Kolyma Karnic contains rare representatives of Mojsvaroceras, Acanthinites, Anasirenites, which are more characteristic for the upper Karnic beds.

Thus, as shown by a review of the lower group fauna, the majority of forms, especially the ammonites, suggest a Karnic age for the deposits, most likely correlative with the Trachyceras aonoides zone of the Alpine Triassic.

The upper group of the Karnic stage, comparatively thin (200 to 700 m), is characterized by a fauna less diversified than that of the lower group, by a wide distribution of endemic forms, and by a small cephalopod content. The pelecypod content of this group sharply increases at the expense of other fossil groups. Brachiopods are in second place, followed by other animal groups.

Crinoids are represented by the same forms of genus Isocrinus which show a great similarity with I. californicus Clark, from the upper part of the North American Karnic

Among the upper group brachiopods, belonging to family Rhynchonella Gray, are Omolonella omolonensis Moiss., a native form; cf. superba Bittn., occurring chiefly in the upper part of the Timor and Alpine Karnic; R. aff. sumrimkinensis Krumb., whose related form is known from the lower Karnic of Timor.

Considerably less diversified are families Spiriferinidae Davidson and Terebratulidae Ling. The first is represented by a widely distributed species, Spiriferina aff. pittensis Smith, typical of the upper Karnic beds and lower part of the Noric stage of Alaska and California, also of the upper part of the Maritime Province Karnic; the second family is represented by Zellerina kolymensis Moiss., known from the Karnic of the Maritime Province, U.S.S.R.

Among the pelecypods of the upper group, which belong essentially to the same genera as they do in the lower group, appear representatives of new genera, Pleuromya, Oxytoma, Pseudomonotis, Posidonia, Gryphaea, and Leurophorus.

Widely developed in the upper group are Ardinia ovula Kittl and C. indigirensis Kittl. Extremely rare is Maophoria solitaria Bittn., associated with the upper Karnic Alpine zone. Poorly distributed is Pleuromya humboldti Gabb., known from the Tropites subbulatus zone of California.

Among the Aviculidae of the upper group, four species belong to genus Oxytoma: Oxytoma mojsisovičsi Tell., O. czekanowskii Tell., O. omolonense Kipar., O. zitteli Tell., which also occur in the upper Karnic deposits of the Far East of the U.S.S.R. and Japan (Halobia - Tosapecten beds).

The genus Monotis includes three species, all are in the upper group: Monotis scutiformis var. typica Kipar., M. donnellaeformis Kipar., M. (Anaucella) ussuriensis Vor. These species are associated not only with the upper Karnic deposits of northeastern Asia, but with those of the Far East U.S.S.R.

In some places Posidonia stella Gabb, of the Tropites subbulatus zone of California occurs. Family Halobiidae Kittl is represented essentially by the same Halobia species as in the lower Karnic group. Predominant in the upper group are Halobia celica Mojs., H. colymensis Kipar., H. fallx Mojs., H. superbescens Kittl, H. cordiliferana Smith. The vast majority occur in the upper Karnic beds, in the Tropites subbulatus zone of North America and the Mediterranean Province.

Family Pectinidae is represented by but a

few species, the widest distributed among them being Pecten (Eupecten) subhiemalis Kipar., P. (Eupecten) suzukii Kob., and P. (Entolium) kolymensis Kipar. These pecten species are characteristic for the faunal assemblages of the Upper Karnic and Rhaetic deposits of northeastern Asia. Moreover, they are known from the upper Karnic of the Far East U.S.S.R. and from the Halobia-Tosapecten beds of Japan.

Gryphaeae occur in both the upper Karnic and the lower Noric beds, most commonly in shell banks. They are more diversified in the former, with five species: Gryphaea arcuataeformis Kipar., G. sculd Böhm, G. keilhaui Böhm, G. Sibirica Vial. With the exception of native species described by L.D. Kiparisova, the others are characteristic for the Karnic of Bear Island, Spitzbergen, and Ellesmere Land.

Cephalopods are represented poorly, both as to genera and to species. In this faunal complex, they are noncharacteristic and rare. Comparatively more common is genus Sagenites and certain Nautiloidea. The representatives of the first belong to group Sagenites reticulata Mojs., known from the upper Karnic Tropites subbulatus zone of Timor, Himalayas, and the Alpine lower Noric. Of the other ammonite genera, only a few specimens of Mojsvarocera cf. turneri Hyatt and Smith were found, associated with the California zone of Tropites subbulatus, and solitary specimens of Anasirenites.

Thus, the upper Karnic age of this group is determined from the fauna cited, on the basis of the appearance of new genera and species which are also found in the lower Noric where they become dominant. The lower upper Karnic boundary is drawn at the total disappearance of ammonites of genus Sirenites, from the S. senticosus Dittm. group. Its upper boundary is drawn at the disappearance of typical Karnic Halobia. In a majority of cases, it is the base of the overlying shell limestones consisting of Monotis scutiformis var. typica Kipar.

It should be noted, however, that the paleontologic evidence for this portion of the Karnic section of northeastern U.S.S.R. is inadequate. As regards its position between the deposits whose age is indisputable, considering also the sequence of its component groups, the identity of the upper group and its upper Karnic age are undisputed. As to whether it belongs to the Tropites subbulatus zone of the Hallstätterkalk of the eastern Alps, remains unclear, as yet. The data for a final judgment are inadequate. In volume, it only approaches the eastern Alps Karnic.

System	Division	Stage	Zone	Boreal Basin		Peripheral Pacific Basin				Mediterranean Geosynclinal Basin		
Triassic	Upper	Karnic	Trachyceras aonoides	Shales, siltstones, and sandstones with Halobia zitteli, H. superba, H. charlyana, Sirenites seneticosus, Clionites, Arcestes	Lower Monogugai series with Neocalamites carrel, Taeniopteris	Limestones with Halobia superba, Sirenites hayesi, Trachyceras	Calcareous shales with Halobia subperba, Trachyceras	Siliceous shales with Proacrestes bicarinatus	Beds with Sirenites aff. senticassiana, H. charlyana, H. moluccana	Limestones with Halobia	Gray beds with Trachyceras, Monophyllites, Sirenites limestone with Halobia comata, Joannites	Limestones with Trachyceras aonoides, Sirenites senticosus, S. sirifalcatatus, Clionites
				Trachyceras aonides	Siltstones with Daonella, Nathorstites indigirites, Monophyllites	Daonella with Rymnoceras	Sandy limestones of the Dawsonites zone with Nathorstites	Shales with Halobia rugosa, Trachyceras storrsi	Sandstones and shales with Daonella	Limestones with Halobia comatoides, Myophoria	Beds with Daonella indica	Limestones and dolomites with Trachyceras aonibes Daonella, Halobia vixaurita
				Worthenia solitaria	Beds with Halobia salinarium, Monotis scutiformis	Upper Monogugai series	Coral limestones	Coral zone with Thecosmilia, Isastrea	Ss, sh, and conglomerates with Monotis okhotica and Arcestes near base	Limestones with Halobia lineata, H. salinarum	Limestones with Halobites, Tibetites, Juavites	Limestones with Pinaceras, Cladiscites, Halobia salinarum
				Tropites subbulatus	Siltstones and shales with Halobia celtica, Oxytoma, Monotis	Lower Pseudomonotis series with Oxytoma, Pecten, Gryphaea, Zeilleria	Limestones with Halobia cordillerana, Pleurophorus, Tropites	Limestones with Juavites, Halobia cordillerana, Trachyceras	Limestones with Proacrestes Jygo, sh and ss with Pecten suzukii, Oxytoma Myoconcha (Toza), shale with Halobia	Limestones with Halobia superba, H. austriaca, Tropites subbulatus	Limestones with Daonella styriaca, Tropites subbulatus	Limestones with Tropites subbulatus, Halobia suessi, H. fallax

It is clear from the above review that the northeastern Asia Karnic is strongly influenced by the elements of the Alpine and Himalayan provinces. The wide distribution of certain Karnic pelecypods, the most typical of which are *Halobia*, also cephalopods *Clionites*, *Sirenites*, *Anasirenites*, *Trachyceras*, *Analacites*, *Placites*, *Arcestes*, and *Pinacoceras*, suggests a wide intercommunication and migration of faunas.

A correlation of these faunas with the Karnic faunas of other countries and provinces (see Table) helps to trace the migration paths for this fauna and provides a possible connection between its habitat basin and other geosynclinal provinces.

Such a correlation of cephalopod faunas clearly establishes a connection of our Karnic basin with a Karnic sea which has left its deposits in the arctic and subarctic provinces, on one hand; and with the basins of the Mediterranean geosyncline, on the other.

With the European basin of the Mediter-

anean geosyncline (western Tethys), where our animal groups are broadly represented, this connection appears to have been accomplished along the west coast of North America by way of Central America and the Atlantic.

Considering the abundance in the Karnic of North America, of representatives of genera *Halobia*, *Trachyceras*, *Clionites*, *Sirenites*, and other fossils in the Alpine Triassic, an immeasurably greater connection of this fauna with the Alpine, and an insignificant development of this animal group in the Himalayas, our assumption is very reasonable.

The path across the Arctic basin to the Mediterranean province of Europe was barred by an immense land mass comprising the northern part of the European continent, a considerable segment of Siberia, and most of North America on the Atlantic side. Communication with the east Tethys was difficult, effected chiefly by way of Japan, south to the Indo-Australian archipelago, and thence

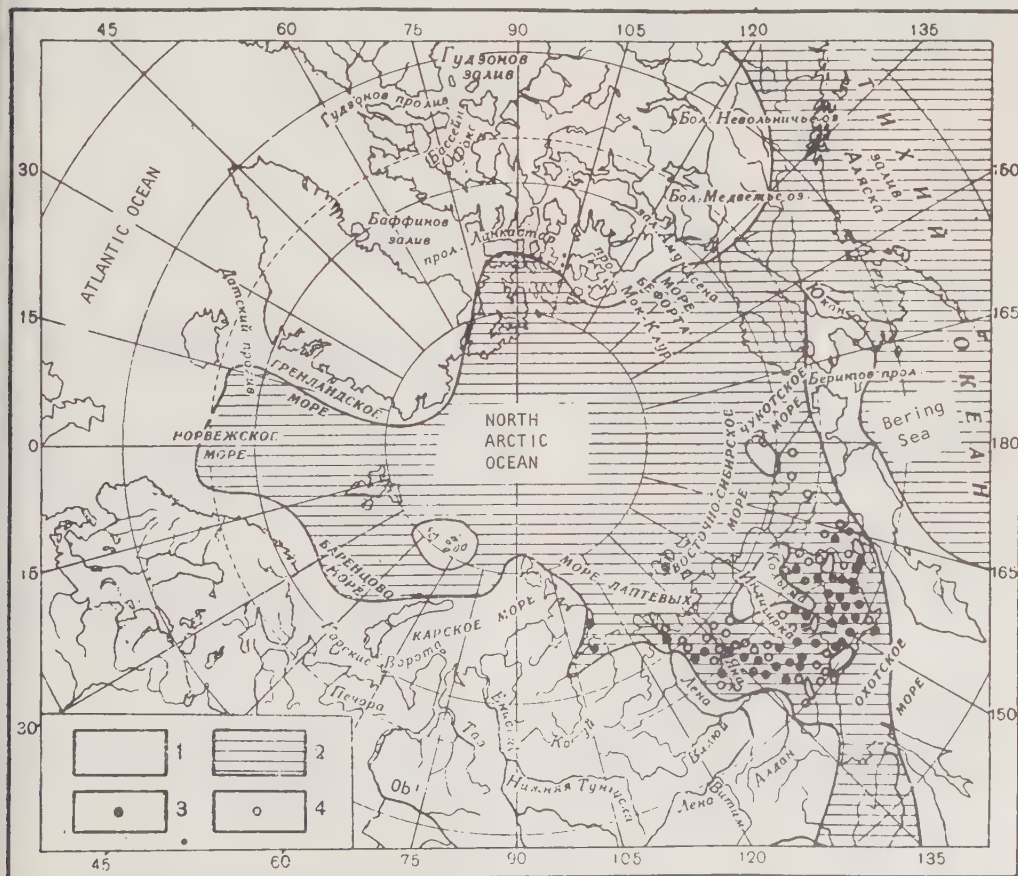


FIGURE 1. Distribution of Karnic Sea.

1 -- land; 2 -- sea; 3 -- fauna of lower Karnic stage; 4 -- fauna of upper Karnic stage.

to the Himalayas and Pamirs.

The Karnic transgression, advancing from the north, reached the Ussuri region and penetrated the Trans-Baikal only toward the very end of the Karnic epoch, having left behind deposits with rare *Halobia*, *Monotis scutiformis* var. *Kipar.* (Fig. 1).

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BRIEF COMMUNICATIONS

SIMPLE LABORATORY EXPERIMENTS DEMONSTRATING INFILTRATIONAL METASOMATIC ZONATION

by

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and
S. A. Brusilovskiy

In recent years, D.S. Korzhinskiy has developed a theory of infiltrational metasomatism, based on physical chemistry.¹ According to this theory, under certain natural solution, infiltration conditions, rock zones emerge, sharply separated from each other and differing in mineral composition. In this process, the interaction of the solution and the rock only takes place in the zone boundary, so that in metasomatism the length of the zones alters, rather than their composition.

The conditions for the formation of such zonation are as follows: a) the speed of the establishment of a balance between the solution and the solid phase is greater than that for the solution infiltration; b) the rock is of uniform porosity.

D.S. Korzhinskiy's works fully corroborate the above-mentioned property of infiltrational zonation. Similar phenomena are likewise observed in various chromatographic columns widely used in laboratory practice. Nevertheless, the physical-chemical possibility of formation of a metasomatic zonation, as postulated by D.S. Korzhinskiy, in itself has been disputed by some geologists.

For this reason, we give a description of a few simple experiments demonstrating infiltration zonation as formed under laboratory conditions, by using some appropriate dyed salts.

The experiments were performed with an apparatus, illustrated in Figure 1, and consisting of a glass tube 1 (diameter, 15 to 25 mm) fastened to a conventional stand, and glass jar 2 with a lower outlet and a faucet.

The lower part of tube 1 is connected by a rubber hose to a thin glass tube 3, whose upper end is bent back. Tube 1 is filled with the "rock" which is in a pulverized mixture of appropriate crystalline materials. The solution slowly seeps from jar 2 through tube 1, and out through nozzle 3. The velocity of flow is regulated by the change in position of this tube 3. Its lowering increases the hydrostatic head and the velocity of the flow. Thus, the seeping through of the solution can be regulated at flow rates as low as one drop per 2 to 10 min.

The success of the experiment depends to a considerable degree on uniform seeping of the solution throughout the entire "rock" cross section in tube 1. To achieve that, the solid mixture should be distributed as evenly as possible throughout the tube, and moistened

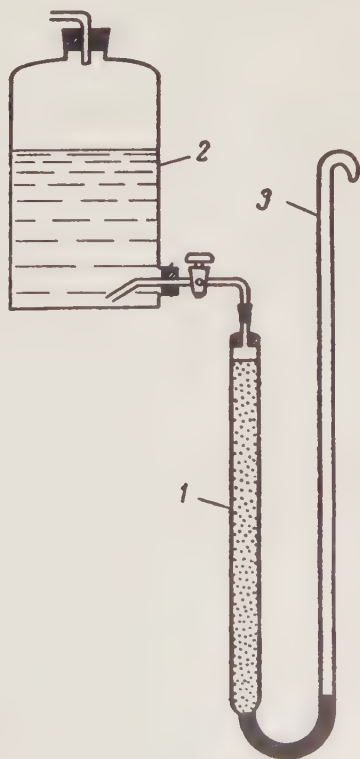


FIGURE 1

¹D.S. Korzhinskiy, Infiltrational metasomatic zonation and vein formation. *Izv. Akademiya Nauk SSR, ser. geol.*, no. 6, 1956.

by the solution to eliminate air bubbles. The powder is moistened from the bottom up, by disconnecting jar 2. A funnel is attached to end 3 (by a rubber hose), tube 3 is lowered, and the solution is slowly poured in. As tube 1 fills up, tube 3 is raised. In order not to bring about a solution of the materials, the moistening of the powder in the lower part of tube is accomplished with liquid components of the "rock." After tube 1 has been filled, it is connected to jar 2, and the position of nozzle 3 is so chosen as to provide a seeping rate of 1 drop per 2 to 10 min.

The experiments were carried on with a mixture of 80% pulverized quartz and 20% potassium bichromate ($K_2Cr_2O_7$), with seeping pure water; and 60% pulverized quartz and 40% potassium chromate (K_2CrO_4) with seeping 10% solution of H_2SO_4 or HNO_3 .

In the first case, two zones were formed in the tube, 2 to 3 hours after the beginning of the experiment: a white, upper one, made up by a single mineral, quartz; and an orange, lower one, carrying two minerals, quartz and solid $K_2Cr_2O_7$. The boundary between the zones was very sharp. It gradually shifted downward, so that the upper zone grew deeper while the lower grew shallower. No other changes were observed in the zones, during the seepage. Their color remained the same, throughout their respective lengths.

In the second case, three zones were formed.

1. A white, upper zone, consisting of a single mineral, quartz.

2. A middle, orange zone, of two minerals: quartz and potassium bichromate which had been formed from the chromate of the lower zone, through reaction $2K_2CrO_4$ (solid) + H_2SO_4 (solution) = $K_2Cr_2O_7$ (sd.) + K_2SO_4 (solut).

3. A yellow, lower zone, preserving the original "rock:" quartz-potassium chromate mixture

The boundaries of the zones were quite definite, gradually shifting downward. No changes in their color were observed.

Judging by the described results, our experiment reproduced the formation conditions for an infiltration metasomatic zonation, as postulated by D. S. Korzhinskiy. Apparently, the solution filtration was sufficiently slow, whereas the speed of $K_2Cr_2O_7$ solution was so great that water seeping through the layer of SiO_2 + $K_2Cr_2O_7$ mixture, about 1 to 2 mm thick,¹ achieved a balance with the solid phase (saturated with bichromate). Therefore, a further seeping of the solution into the lower layers of the "rock" caused no changes in the latter.

Similar relationships took place in the experiments with three zones. In that case, however, besides the solution of the "minerals," a "reactive replacement" of one "mineral" (K_2CrO_4) by the other ($K_2Cr_2O_7$) took place on one of the boundaries.

¹Approximate boundary thickness in our experiments.

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FROM THE HISTORY OF GEOLOGIC SCIENCES

MEMORABLE DATES FOR OCTOBER-NOVEMBER 1958,
REVIEW 23.

SESQUICENTENNIAL ANNIVERSARY OF P. A. CHIKHACHEV

The outstanding Russian geologist and traveler, Peter Aleksandrovich Chikhachev, was born in Gatchine, in 1808. He received his education at home, then specialized abroad, attending lectures by C. F. Naumann and J. A. Breithaupt, in Freiberg; by L. Buch and G. Rose, in Berlin; and later on, by L. Ely de Beaumont, in Paris. Having thus acquired his qualification as a geologist, he kept in touch with his teachers, as well as with the most outstanding scientists of the time - P. I. Murchison, A. Verneuil, and E. A. d'Archiac. P. A. Chikhachev spent most of his life abroad; in diplomatic service for a while, then in travel, chiefly at his own expense.

His first important geologic studies were carried on in Italy and South France (1839-1841), where he collected ample factual material. His map of the Apenning Peninsula was of great scientific interest and immediately attracted the attention of foreign scientists to the young Russian explorer. In his papers on the geology of that territory, P. A. Chikhachev, basing it on an extensive fauna catalogue, proposed a more detailed differentiation of the local Tertiary deposits, than any previously available ones. Some of his conclusions were of prime theoretical importance; for instance, he noted a gradual faunal change in the transition from one stratigraphic stratum to another, and he emphasized that this was in direct opposition to the then reigning ideas of the catastrophists on the presence of sharp paleontologic boundaries. His individual conclusions were undoubtedly influenced by the recently published book by C. Lyell.

In 1842, P. A. Chikhachev visited the Altai and Kuznetsk depression, where he made broad geologic studies and assembled extensive collections. He recognized that the long known coal exposure there belonged to a thick and widely distributed series, and he emphasized the high quality of the Kuznetsk coal and its inexhaustible supply.

P. A. Chikhachev set forth the result of this expedition in a two-volume monograph, published in French, in 1845. In reviewing this work the outstanding contemporary geologists, A. Brogniart, P. Dufrenoy, and L. Ely Beaumont, highly praised it, especially emphasizing Chikhachev's achievement in working out the stratigraphy and geologic history of the Altai.

In 1847-1863, P. A. Chikhachev explored Asia Minor. He worked over his mineral and paleontologic Asia Minor collection in cooperation with some of the outstanding west European scientists, experts on various fossil groups. He published his vast data on Turkey as a monumental eight-volume work, "Asia-Mineure" (1853-1869), which became the first compilation of geology, geography, climatology, botany, zoology, and archeology of Asia Minor. A number of Turkish areas have not been studied by other geologists since Chikhachev; and the name of this Russian explorer still remains in the most recent general geologic maps of that country.

In 1878, P. A. Chikhachev visited Algeria and Tunisia. His observations in North Africa were chiefly geographic; their results have been published in a number of editions.

A recognition of his scientific achievements was expressed in his election to honorary membership of the Petersburg, Berlin, and Munich Academies of Sciences, and many other scientific societies of various countries.

P. A. Chikhachev died Oct. 1, 1890, in Italy, where he spent his last years.

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SESQUICENTENNIAL ANNIVERSARY
OF THE GERMAN GEOLOGIST
B. COTTA

Carl Bernhard von Cotta was born Oct. 24, 1808, in Zillbach (Thuringia). In 1831 he graduated from the Freiberg Mining Academy, and then obtained his Ph.D. degree in Heidelberg. For over 30 years, beginning with 1842, he was Professor at Freiberg Academy, lecturing in geology, paleontology, and ore deposits. His first paper, published in 1832, dealt with a detailed description of some petrified plants.

Later on, in 1832-1848, B. Cotta carried on a geologic survey of Saxony and Thuringia. His geologic maps covering large areas of Germany were distinguished by their precision and detail. He successfully solved complicated problems in stratigraphy and tectonics and paid particular attention to a comprehensive study of ore deposits. Outside of Germany, he visited many ancient mining areas of Europe, specifically the East Alps, Hungary, Banat, and Bucovina.

B. Cotta put great emphasis on the problem of vein origin, developing a theory postulating the vein sulfide ore genesis as a result of precipitation of metalliferous matter, from postmagmatic solutions circulating in fissures. He connected, in one way or another, the formation of metallic ores with intrusive phenomena, emphasizing however that pure metallic deposits are a great rarity and that a majority of ore deposits had originated from below, in vapors or thermal solutions. In the middle of the last century, B. Cotta was hailed as the outstanding authority on the origin of ore deposits.

As a leading expert, he was invited by the Russian government, in 1868, to become acquainted with the geology and metallogeny of the Altai. As a result of his investigations during one field season, he published a voluminous monograph, "Der Altai" (1871), setting forth vast data on rocks and ore deposits. Taking advantage of and systematizing to a considerable degree the diversified and numerous data by the Altai engineers, he confirmed the essential correctness of the Russian ideas on the origin and possibilities of the major deposits.

In his studies of metalliferous ores, he attached great importance to the enclosing rocks. Because of that, his petrographic studies were always penetrating, dealing not only with the mineralogy of the rocks but also with their genesis, which involved complex problems in petrology. In 1855, he published a textbook of petrography, "Die Gesteinslehre," in which he adhered to C.F. Naumann's classification, one of the

most progressive of that time.

In his scientific views, B. Cotta followed the evolutionists. He held in great esteem Lyell's works, and he emphasized in his own works the gradual and continuous process of natural development, pointing to a close interrelationship between the organic world and its environment. Thus, he published a number of papers on the effect of soil composition on population. After the appearance of the "Origin of the Species," B. Cotta attempted to apply the Darwinian principles to the inorganic world.

Well known were B. Cotta's popular writings intended to propagate geologic knowledge. Some of them were also published in Russian.

He died September 15, 1879.

ONE HUNDRED
AND TWENTY-FIFTH ANNIVERSARY
OF THE FOUNDING OF T.G. SHEVCHENKO
KIEV STATE UNIVERSITY

On November 20 (8), 1833, the Ukaz (Order) to found the Kiev University was signed.¹ From the very beginning, natural sciences, including geology, were prominent in the curricula. Its first dean was M.A. Maksimovich, a leader of the progressive movement in the University, one of the outstanding Russian evolutionists of the pre-Darwin period.

In 1834-1836, mineralogy and geology were taught by S.F. Zenovich who extensively used V.M. Severigin's works, for his lectures. The chain (professorship) was then taken over by E.K. Hoffman (up to 1842), one of the pioneer investigators of the south of Ukraina, noted for his important geologic expeditions to Arctic Urals and other little-known regions of Russia, also by his participation in the round-the-world journey of O. Ye. Kotsebu.

Of especial importance in the organization of the Kiev geological school was the long teaching and scientific activity of K.M. Feofilaktov (from 1845 to 1891), one of the founders, and chairman of long standing, of the Society of Natural Scientists of Kiev University. K.M. Feofilaktov, a pupil of D.I. Sokolov, developed advanced ideas in geology in his teaching and practical activity. His works on the geology of the Ukraine were an important step toward the knowledge of mineral wealth of that country, and his

¹The public opening took place June 27 (15); instruction began in September, 1834.

geologic map of the Kiev province and his studies of the Podol'ya crystalline massif have become standard texts for other Kiev geologists.

Among the pupils of K.M. Feofilaktov, and followers of his scientific school, were P.A. Tutkovskiy, V.I. Luchitskiy, P.N. and V.N. Chirvinskiy, V. Ye. Tarasenko, and other notable Soviet scientists. From among them has been selected the geologic and teaching staff, not only for the Kiev University, but for many other teaching and research institutions.

After the retirement of K.M. Feofilaktov, the chair of geology was divided: P.N. Venyukov took over the teaching of geology; and P. Ya. Armashevskiy, that of mineralogy. The former is well known for his work on the paleontology and stratigraphy of Silurian deposits; the latter, for his mineralogic and stratigraphic studies of various regions of the Ukraine.

In 1904-1912, the chair of geology was headed by N.I. Andrusov, an outstanding paleontologists and stratigrapher, and a student of the south Russian and Caucasian Neogene.

The fruitful activity of these scientists promoted the success of the Kiev geologic school whose representatives made many valuable scientific contributions. Thus, V. Ye. Tarasenko assembled and organized vast material on the petrography and mineralogy of the entire South Russian crystalline massif, and took an active part in the making of the geologic and mining map of the Krivoy Rog iron ore basin.

P.A. Tutkovskiy is the author of many interesting papers in various branches of geology, particularly on the morphology and geologic structure of several regions of the Ukraine, also on the problem of loess origin. He was the first in our country, to apply the micropaleontologic method to the study of sediments.

V.I. Luchitskiy carried on extensive regional petrographic studies and compiled, in cooperation with P.I. Lebedev, the first fundamental manual of the petrography of the Ukraine (1934).

Of great scientific interest are the works of P.N. Chirvinskiy, B.L. Lichkov, and many others, younger geologist pupils of the Kiev school, who are taking their place in the development of modern geologic science and in building up the cadres.

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ONE HUNDRED AND TWENTY-FIFTH ANNIVERSARY OF A.I. ANTIPOV

The noted geologist and prominent figure in the Russian mining industry, Aleksey Ivanovich Antipov, was born in 1833, at the Dedyukhin factory (Urals). In 1853 he graduated from the Institute of Mining Engineers Corps, in Petersburg, and was assigned to the South Urals where, in 1854-1855, he was active in geologic explorations in connection with a study of the brown coal deposits of the area. In 1860-1861, he was sent to Saxony, Bohemia, and England, to familiarize himself with the mining industry of those countries.

From 1862 to 1870, A.I. Antipov worked in the Donbas, first as an inspector, then as manager of the mining and salt works of the Don Cossack Province; later on, he was transferred to Petersburg, where he retired in 1889.

The first major work by A.I. Antipov, in collaboration with N.G. Meglitskiy, on the South Urals, attracted immediate attention by the abundance and diversity of its theoretical premises. The Paleozoic stratigraphy of the area was substantially refined, many individual magmatic phases dated, and the first tectonic scheme of the South Urals constructed. Of great scientific interest was his geomorphologic analysis of the area, also the conclusions of the tectonic origin of cleavage and on the origin of folding as a combined effect of vertical movement and tangential pressure. In its stratigraphic and tectonic interpretations, as well as in its theoretical conclusions, the monograph, "Geognostic description of the South Urals ridge" (1858), was a considerable advance in contemporaneous geologic thought. In 1859, the Academy granted the Demidov prize to this work.

The emphasis of A.I. Antipov's study of the South Urals was on coal measures. It was in this field that he carried on his later studies: in 1857 he was directed to study the coal prospects of the Pechora basin. The results were set forth in a number of his papers on the geology of the Pechora region.

A.I. Antipov worked for a number of years in the Donbas. Here he studied various ore deposits, but his main efforts were directed to coal. He directed and actively participated in the great project of geologic mapping of the exploited and prospective areas. A result of this work was the

"Formation map of coal measures of the Don Cossack Province," scale 1:126,000, on 12 sheets (1869-1872). This map clearly illustrated the productive Carboniferous exposures, and the formations overlying the coal measures. For many decades, up to the time of L.I. Lutugin's work, this map was widely used by the Donets geologists, and was favorably regarded abroad.

From 1864 on, A.I. Antipov was a member of the Mineralogical Society, where he was very active. In 1907 he fell ill, and died at the end of 1913.

During his illness, his wife A.I. Antipova gave a sum of 2,500 rubles to the Mineralogical Society, to reward the best papers in the Russian language, on mineralogy, geology, and paleontology. In 1908, the Society established the A.I. Antipov medal, to be awarded biannually. In 1925, at the suggestion of A.K. Boldyrev, the medal was replaced by the A.I. Antipov certificate of merit. Among its recipients were L.S. Librovich (1927) and S.A. Yakovlev (1928).

ONE HUNDRED
AND TWENTY-FIVE YEARS
AFTER THE PUBLICATION
OF THE FIRST RUSSIAN LANGUAGE TEXT
ON PALEOBOTANY

In 1833 a book by Yakim Grigor'evich Zembnitskiy appeared, "Brief manual to the systematic determination of fossil plants occurring in various parts of the globe." The author, a paleontology teacher in several Petersburg schools had done much to propagate the science of fossil organisms among the Russian geologists and biologists. In his manual of paleobotany, Ya. G. Zembnitskiy compiled a description of fossil plants, chiefly from various writings of A. Brogniart, and he organized his material after that French scientist.

Inasmuch as there was no Russian paleobotanic terminology at that time, Ya. G. Zembnitskiy proposed a number of new names, many of which he borrowed from botany. Subsequently, many of them persisted into the modern scientific literature. Momentous for that time was the author's suggestion that a fossil flora may be an indication of ancient climatic conditions.

Ya. G. Zembnitskiy did not share the then-prevailing catastrophic ideas, and adhered to a progressive development of the organic world. In his Manual he pointed out the evolution of flora, from the lower to the higher forms, noting that, as a result of uninterrupted progress, all fossil forms

differ from the living.

Ya. G. Zembnitskiy's book, because of its extensive factual material and because of the author's advanced ideas, played an important part in the history of Russian paleobotany. As rightly noted by A.N. Krishtofovich, "Ya. G. Zembnitskiy's judgment on the nature of fossil plants and on the problems of paleobotany was so correct that many of his utterances would not be out of place in a modern textbook."

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SEVENTY-FIFTH MEMORIAL
OF THE PALEONTOLOGIST,
J. BARRANDE

Joachim Barrande was born at Saugues (France), August 11, 1799. He graduated from the École Polytechnique, in Paris. In early 1820, he moved to Bohemia where he was first a teacher; then, in 1833, engaged in the construction of a horse-drawn railroad. While building the roadway, he became interested in paleontology, and extended the field of his exploration over the whole of Bohemia. As a result of detailed investigations, he succeeded in working out the stratigraphy of the Bohemian Silurian and in correlating these deposits with the synchronous deposits of England.

J. Barrande painstakingly studied his vast paleontologic Silurian collections, and separated many previously unknown forms. He set forth the results of his work of many years, in a monograph: "Système silurien du centre de la Bohême," Prague et Paris, 1852-1881, consisting of 22 volumes, with some 6,000 pages of text and 1,160 figures. This colossal opus contains excellent descriptions and illustrations of various fossil groups: trilobites, cephalopods, pteropods, brachiopods, ostracods, pelecypods. The excellence and scope of the material and illustrations brought the author a well-earned fame. His standard collections - his gift to the Paris Museum - and his paleontologic descriptions have preserved their scientific value up to our time.

SKETCH OF THE LIFE OF JOACHIM BARRANDE OF PRAGUE. The Geological Magazine, New Series, vol. X, no. XII, p. 529-533.

FROM THE HISTORY OF GEOLOGIC SCIENCES

FIFTIETH MEMORIAL OF ACADEMICIAN F. B. SCHMIDT

Fifty years ago, Nov. 1908, Academician
Fedor Bogdanovich Schmidt died. For a brief
biographic and scientific review of his career,
see Zvestiya Academy of Sciences U. S. S. R.
Izv. Akad. Nauk SSSR, Ser. Geol., no. 6, 1953.

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REVIEWS AND DISCUSSIONS

N. A. MARINOV'S BOOK, "STRATIGRAPHY
OF THE MONGOLIAN PEOPLE'S REPUBLIC,"
AND GEOLOGIC MAP
OF THE MONGOLIAN PEOPLE'S REPUBLIC,
SCALE 1:2, 500, 000

by

R. A. Khasin

The recently published monograph by N. A. Marinov, "Stratigraphy of the Mongolian People's Republic," by the Academy of Sciences U. S. S. R. Press (Academician V. A. Obruchev, Editor-in-Chief; N. S. Zaytsev, Editor), and the Geologic Map of the Mongolian People's Republic, Scale 1:2, 500, 000, by the Gosgeoltechizdat [State Geologo-Technical Press] (V. A. Obruchev, Editor-in-Chief; acting editor, N. A. Marinov), is an excellent compilation of all data extant on the stratigraphy of the M. P. R. These data have been accumulated in more than 30 years of study by Soviet and Mongol geologists. The work under review fills a glaring gap in the geologic literature on Central Asia, a lack which greatly hindered the understanding of the problems of paleogeography, tectonics, magmatism, and metallogeny, not for the M. P. R. alone, but also for the adjacent vast provinces.

The few previously published works only touched upon some local problems (papers by N. A. Marinov, S. N. Alekseychik, A. Ya. Stefanenko, A. D. Kalenov, A. Kh. Ivanov, R. A. Khasin, I. Ya. Yefremov), or else dealt with the geologic structure of more or less extended areas (papers by A. Kh. Ivanov, N. A. Marinov, R. A. Khasin, V. M. Sinitsin).

V. A. Obruchev's works, chiefly based as they were on road geology done at the end of the last century, although touching upon principles of Central Asian geology, naturally could not embrace all of the immense material subsequently assembled, on Mongolia itself or on the adjacent provinces of the Soviet Union and China.

The Marinov monograph and the first geologic map of Mongolia, in which factual material is used with a comprehensive scientific objectivity, are the much-needed

culmination of the geologic study of that country. Such an all-embracing work, which has taken 10 years of painstaking effort, greatly facilitates the further geologic study of Mongolia, that vast and most interesting region of Central Asia.

In the monograph, after two brief sketches on the history of geological and orographic study of the M. P. R., the author discusses its stratigraphy, along one section. A short review is given of the history of study of each period of the Paleozoic and general information as to their distribution is provided; then numerous sections are described with detailed paleontology and major folded structures of each system of subdivision are described. Finally, general characteristics are summarized with correlation charts for stratigraphic complexes for various parts of the country, and in some instances for adjacent provinces of the U. S. S. R. and China. The conditions of sediment accumulation, tectonics, and volcanic activity are described.

The Mesozoic and Cenozoic deposits, because of their great development throughout Eastern and Southeastern Mongolia, and because of their being better known, are dealt with not by regions but, depending on the degree of their stratigraphic differentiation, by subdivisions (for the Tertiary) or by series (for Jurassic and Cretaceous deposits).

The concluding chapter gives a composite stratigraphic scheme of the M. P. R., a brief historic-geology sketch, and a list of problems requiring further study.

It is natural that, inasmuch as such folded structures as the Mongol Altai, Prikosogol'ye, Khanghay, Kentey, and others are complex and consist of a number of structural-facial zones, at times substantially differing from each other in their geologic history, any characteristic of individual stratigraphic complexes throughout these major provinces would reflect only their generalized stratigraphic sections.

The poor knowledge of the M. P. R., especially as far as the ancient (Precambrian and all of the Paleozoic) complexes are concerned, prevented the author from providing a detailed stratigraphic analysis by individual

structural-facial zones; however, he attempts, as far as his material allows, to determine the nature and thickness of the sediments in various parts of the subject regions.

We shall take up, in more detail, some problems of Mongolian stratigraphy:

1. The author quite correctly points out the inconsistency of the ideas of M.A. Usov and of the American geologists, Berkey and Morris, on the wide development of Precambrian rocks in Mongolia, inasmuch as later studies have convincingly demonstrated a Paleozoic age for the alleged Precambrian sand-schist deposits.

In this connection, a Precambrian age assigned by A. Kh. Ivanov, however conditionally, to a metamorphic series of the Mongol Altai, developed west and northwest of Mt. Kobdo, is hardly justified. Their age is rather, Ordovician (or Cambrian), which is in accordance with an extensive development of Ordovician deposits in the area of the Bain-Ul'gey ridge, and with the general structure of the Mongol Altai.

2. The meaning of the term "lower Paleozoic," especially for East Mongolia, is unfortunately not clear, because of a lack of field data.

Most recent studies have yielded nothing new on the stratigraphy of that undifferentiated complex. An absence of paleontologically determined Cambrian in the east of the country, renders a Cambrian age of these deposits hardly probable. It appears that most of the formations described as Lower Paleozoic by many investigators, should be relegated to Precambrian, with their smaller portion (relatively less metamorphosed) to the Silurian.

3. Unfortunately, the author could not use new data, obtained by V.A. Amontov in 1955-1956, on the Precambrian of the Ozer-naya depression. Therefore, these deposits are not discussed in the text, but represented on the geologic map, published shortly after the monograph. According to V.A. Amontov's data, they are represented by volcanic formations and reef limestones with lower Cambrian Archaeocyathids.

4. The wide development throughout Mongolia, especially in Kentey and Khanghay, chiefly of terrigenous, undifferentiated middle Paleozoic formations, once more exposes our poor knowledge of Mongolian stratigraphy.

A study of East Mongolia shows that this complex embraces diverse stratigraphic elements, from Silurian to and including Carboniferous (locally to Permian), which, in

his time, was pointed out by V.A. Obruchev. It should be added that, although these deposits are represented almost exclusively by thick terrigenous sediments in the Khangay-Kentey meta-anticlinal structure-facial zone, their equivalents in the East Mongolian synclinal zone occur alongside widely developed volcanic and carbonate formations. The presence of the latter facilitated the differentiation of the middle Paleozoic of this zone into individual, faunally characterized, stratigraphic complexes.

5. The role of the Silurian, in the geologic structure of East Mongolia, appears to be underestimated because a part of it is included, by some investigators, in an undifferentiated middle or sometimes lower Paleozoic; also because of widespread Mesozoic formations covering the Paleozoic basement.

6. Without arguing against the importance of the Khanghai fault zone in the formation of structural-facial zones north and south of it, it should be mentioned that the boundary between the Caledonian and Hercynian foldings coincides all along it.

The author had no way of knowing the latest results (1956) of V.A. Amontov's work. They reveal a great development of Cambrian formations throughout the western Khanghay and the Great Lakes depression, where they are overlain, with a sharp angular unconformity, by gently dislocated epicontinental Silurian and Devonian deposits.

The boundary between the Caledonian and Hercynian folded belts passes approximately along the Tsagan-Oloma meridian, veering northwest along the south slopes of the Mongol Altai.

7. The description of the Devonian deposits could have been amplified by new data obtained by A.A. Khrapov in 1956, and therefore unknown to the author.

8. Furthermore, it should be pointed out that the most recent work by N.G. Grazhdantsev, V.S. Soleyev, and G.V. Zorin, in the Nukut-Daban ridge, in the extreme east of the M.P.R., have established the presence of faunally defined Lower Devonian and Lower Carboniferous deposits, the former being previously known only from West Mongolia and Khanghay; and the latter, besides West and Central Mongolia, in the Sayn-Shandy region, south of Dзамын-Удэ and Bayshintu.

In the Great Khinghay, too, no faunally characterized Devonian and Lower Carboniferous deposits have been known. The new findings of Lower Devonian and Lower Carboniferous fauna in the Nukut-Daban ridge,

and its character, lead to a paleogeographic picture of the northwestern part of Central Asia during these stages of middle Paleozoic, somewhat different from that given by N.A. Marinov, on the basis of the material on hand.

The new data suggest that the Lower Devonian sea was not limited to the Mongol Altai and Khanghai highlands, but spread out far to the east, to the outer reaches of Mongolia.

The boundaries of the Lower Carboniferous sea, undoubtedly connected with a sea covering Southeast Mongolia and China, could be shifted considerably to the east.

It appears that Devonian and Lower Carboniferous marine deposits also accumulated in the Great Khinghan region, at least in its northern part, so that the designation as Permian, of widely developed terrigenous deposits here as has been done, is hardly justified in the light of new data. It also becomes obvious that, beginning with Upper Silurian and into Lower Carboniferous, there were no long breaks in sedimentation over northeastern Central Asia, inasmuch as the presence of all stages of the Paleozoic has been established.

9. In his general description of the Jurassic deposits, the author states, "In middle Mesozoic, in connection with the Kimmeridgian phase of tectogenesis, the Paleozoic platform underwent mighty interior downwarps, evidently initiated as early as the upper Paleozoic and Triassic."

This statement does not quite correctly represent the geologic history of individual parts of the country, at the close of Paleozoic to the first half of Mesozoic. The Paleozoic change of a mobile zone to a platform only took place in Central and West Mongolia, while the East Mongolian geosynclinal province was going through its later and final stages of development, featured just by such numerous interior downwarps and foredeeps, with the transformation to a young platform only taking place in the Tertiary.

Because of that, the West and Central Mongolian Jurassic and Cretaceous deposits are much thinner and much more circumscribed than they are in East and South Mongolia.

10. As a result of extensive studies by the Paleontologic Expedition of the Academy of Sciences U.S.S.R., and of detailed geologic surveys, the Cretaceous stratigraphy is the best worked out, chiefly on the basis of numerous flora and fauna collections.

We only note that, according to the most recent studies by A. Kh. Ivanov (1956), the assumption of an extensive Cretaceous development in the Great Lakes depression is not substantiated. Here, in most cases, Tertiary and less commonly continental Jurassic deposits rest directly upon the Paleozoic basement, with the Cretaceous in a comparatively small distribution.

11. The stratigraphic summary of the M.P.R., as given in "Conclusion," is a brief compilation of all extant data on one of the most interesting parts of Central Asia, of which we knew little, up to very recently.

However, we cannot but concur with the author's statement that his concept "with further development of geologic study and accumulation of new data, will undoubtedly be refined, and possibly completely reworked in spots, since many of the problems of Mongolian geology remain unsolved or only partially solved." Nevertheless, N.A. Marinov's monograph is a great contribution to the geology of that country. It undoubtedly will become a handbook for all students of the geology of Mongolia and adjacent countries.

A valuable addition to the monograph is the Geologic Map of the M.P.R., scale 1:2,500,000, published in 1957, and edited by V.A. Obruchev and N.A. Marinov. Although a help in reading and understanding the monograph, the map is unquestionably important in itself. As a synthesis of investigations of many years by Soviet and Mongolian geologists, it facilitates a solution of regional-geologic and metallogenic problems, inasmuch as Mongolia is a focus of such heterogeneous structural-tectonic elements as the Sayan-Altai and the Mongol-Okhotsk folded belts.

Although the map is not of equal value in all its parts, because of the quality and quantity of the data (its western half but poorly known), it distinctly reflects the basic stages of the geologic development of this vast portion of Central Asia: the northwestern Mongolia represents a Caledonian mobile folded belt, with its terminal stage in the Devonian. The boundary between this and the Hercynian mobile belt partly coincides with the Khanghai deep-seated fault, stretching more than 1,000 km through Mongolia, and continuing into Trans-Baikal. Only in western Mongolia does this boundary recede far south, so that the Caledonian province includes West Khanghai and the Great Lakes depression.

An analysis of the map reveals a very interesting feature of the Hercynian mobile belt which stretches over immense distances, from the Gornyy Altai in the west to the

astern Trans-Baikal to the east.

The map clearly shows that the closure of the Hercynian geosynclinal province proceeded gradually from the north to the south and from east to west, so that the development of structural-facial zones in the south and east of this mobile lagged, as a rule, behind the northern and western zones. Consequently, the later and final stages of Hercynian development in West and Central Mongolia fall into the upper Paleozoic, whereas in East and Southeast Mongolia they fall into the upper Mesozoic (Jurassic and Cretaceous).

Accordingly, the Mesozoic history of East Mongolia should be regarded as a belated development of the Hercynian mobile belt, rather than an independent formation of a Mesozoic geosyncline: a southwesterly extension of the East Trans-Baikal Mesozoic mobile belt, as previously thought by many geologists. This predetermines all of the peculiarities of the Mesozoic metallogeny of East Mongolia.

It follows that it is fruitless to attempt to draw any sharp boundaries between the

provinces of Mesozoic and Hercynian folding and, correspondingly, between the Hercynian and Mesozoic metallogenic provinces (A.D. Kalenov).

This first geologic map of the M.P.R. clearly demonstrates the basic shortcomings in the study of that country. Beside the already mentioned generalization of its western portion, insufficiently covered by geologic surveys, there is a glaring inadequacy in the Precambrian and Paleozoic stratigraphy, resulting in vast regions of undifferentiated Precambrian, lower and middle Paleozoic, and at best, in a dating of the deposits only to periods and eras. The situation is no better for the intrusive complexes.

Still, the publication of a geologic map of the M.P.R., sufficiently well related with that for the adjacent part of the Soviet Union, is a great event in the geologic study of that vast land. It will be of great help in the paleogeographical, structural-tectonic, and metallogenic analysis of such folded structures as the Gornyy Altai, Sayany, and Trans-Baikal, and the provinces of China, adjacent to Mongolia.

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CHRONICLE

SECOND ALL-SOVIET PETROGRAPHICAL CONFERENCE

The Second All-Soviet Petrographical Conference was held in Tashkent, May 19-23, 1968. About 1,000 attended, representatives from more than 100 geologic organizations and schools of higher learning of the U.S.S.R., 15 foreign scientists from the Chinese People's Republic, Polish People's Republic, German Democratic Republic, and People's Republics of Rumania and Bulgaria.

On May 19, after a solemn opening ceremony and a few introductory remarks by the Chairman of the Organization Committee, President of The Academy of Sciences of the Uzb.S.S.R., Kh. M. Abdullayev, the members heard a report by the Minister of Geology and Mineral Conservation, U.S.S.R., Ya. Antropov, on the state of knowledge of the territory of the U.S.S.R. and on the problems of petrology.

Some 18 papers were read at the joint sessions, May 20 and 23, including those by the geochemist S. T. Dimitrov (Bulgaria), Smulikowski (Poland), Prof. Kautsch (D.R.), Acad. D. S. Korzhinskiy, corresponding member G. D. Afanas'yev, Yu. A. Kuznetsov, N. A. Yeliseyev, and others.

On May 21 and 22, meetings were held in sections: a) geology and metallogeny of Mesozoic magmatic complexes; b) geology and metallogeny of Mesozoic magmatic complexes; c) problems of alkaline rocks, ultrabasic rocks and dike formations; d) geochemistry, physical chemistry of magmatic and metamorphic complexes, and methods of their study. More than 90 members took part in the meetings and discussions.

Most papers, read both in the joint and sectional meetings, dealt with the regularities of magmatic phenomena in various parts of the U.S.S.R., especially with their metallogeny. General problems of the development and distribution of magmatism were dealt with by Yu. A. Kuznetsov and Yu. M. Sheynin. Their papers suggested a number of conclusions on the character of magmatic and metallogenic phenomena, in parts of the U.S.S.R. More specifically, the authors pointed out as certain the multiple manifestations

of magmatic processes, in Central Asia, and their decisive part in the endogenous ore formation. According to studies (by Kh. M. Abdullayev, Ye. D. Karpova, D. N. Yelyutin, A. A. Konyuk, V. I. Knauf, R. B. Baratov, M. Kh. Khamidov) in Kirghiziya, Uzbekistan, and Tadzhikistan, from three to seven epochs [of magmatism] are recognized (Proterozoic, Ordovician, Devonian, Middle Carboniferous, Upper Carboniferous, Permian, Permo-Triassic, Cretaceous, and Paleogene). These time periods correspond to the appearance of definite magmatic complexes and associated ore-making.

Central Asian geologists recognize also a number of regularities in the distribution of these magmatic complexes and ores. It is of importance that these problems were approached from somewhat new points of view, taking into consideration the peculiarities of the development of the earth's crust, and its structural differentiation within Central Asia.

A number of papers touched upon the problems of the genetic relation of endogenous mineralization to magmatism.

Of considerable interest in this field was a paper by a large group of associates of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, The Academy of Sciences of the U.S.S.R. (V. S. Koptev-Dvornikov, O. S. Polkvay, M. G. Rub, I. E. Smorchkov, F. K. Shipulin), also papers by E. A. Radkevich, I. G. Magak'yan, and S. S. Mkrtchyan (Geology Institute, Academy of Sciences, Arm.S.S.R.), and M. P. Materikov (VIMS).

The timely question of the connection between ore-bearing capacity and effusives was treated in a number of papers (G. S. Dzotsenidze, M. A. Kashkay, Sh. A. Azizebekov, M. A. Favorskaya, A. M. Kalik).

In discussing the features of distribution of magmatic and ore complexes, in space and time, many geologists criticized the present beliefs on the development stages of mobile belts in the earth's crust.

Much new and interesting material was supplied by the students of magmatic forma-

tions in the platform provinces, especially of East Siberia (A.P. Lebedev, G.G. Moor).

Also general problems of the genesis and distribution of alkaline rocks were clarified. Papers by O.A. Vorab'yeva, V.K. Monich, G.P. Bagdasaryan, and others refined our ideas on the properties of alkaline magmatism in individual regions.

A physical chemical treatment of magmatic and postmagmatic formations was presented by D.S. Korzinskiy, V.A. Maslennikov, and I.G. Govorov.

The problem of the genesis and distribution of metamorphic rocks, and their systematics, was treated in papers by Ukrainian geologists (N.P. Semenenko, Ya. N. Belevtsev, S.P. Rodionov). A number of papers dealt with the physico-chemical and mechanical properties of rocks, and methods of their study (B.V. Zalesskiy, B.P. Belikov, Yu. A. Rozanov).

The Conference also discussed the papers on "The problems of petrogenesis in the light of experimental data" (N.I. Khitarov) and "Data on the state of study of absolute age determination of rocks, and their geological significance" (G.D. Afanas'yev).

Many speakers emphasized the necessity of bringing more order into petrographic terminology by a petrographic dictionary, etc.

The May 23rd Joint Session unanimously adapted the resolution, printed below, slightly abridged.

Following the conference (from May 24 to June 1), the members participated in two field trips: 1) Karamazar - West Uzbekistan; 2) North Kirghizia.

RESOLUTION BY THE SECOND ALL-SOVIET PETROGRAPHICAL CONFERENCE TASHKENT, MAY 23, 1958

Five years have passed since the First Petrographic Conference. Many important events took place in the life of our country, during that time. The most momentous was the XX Congress of the Party, which formulated the problems of Soviet science as follows: "To develop science by all means. By extending theoretical investigations over all fields of knowledge, to strengthen the part played by scientific institutions in technical progress and the organization of industry. To reorient the efforts of scientific research institutions toward the immediate

needs of the economy."

By the 40th anniversary of the Great October Revolution, the geologists of our land have achieved considerable successes in the field of supply of mineral raw material to the state economy. Notable scientific generalizations also were achieved, as witness the geologic and tectonic maps of the Union and its individual parts and areas.

The Second Petrographical Conference acknowledges that the problems set forth in the resolution of the First Petrographical Conference, are still valid at the present stage of petrology.

The shortcomings in the field of petrological problems and in the rendering of active help to the solution of essential practical problems as noted by the First Conference, are still with us to a considerable degree. Although the petrographers of the Soviet Union strove valiantly to eliminate the shortcomings noted by the First Conference, its resolution has not been adequately fulfilled. There is a great collective task for all petrographers of the Union, to solve the momentous problems of petrography.

Among the achievements by the Soviet petrographers in the field of regional study of the country, for the last five years, are the following:

Great success in the study of magmatism and metallogeny of the Republic was achieved by the Uzbekistan petrographers who produced a number of comprehensive monographs, in collaboration with field geologists; they published a major work summarizing the petrographic knowledge of that country, also papers bearing on the development of the theory of ore formation and petrology.

The petrographers of Georgia produced a number of interesting works on the magmatism of that country and the problem of granite origin. Extensive factual material has been accumulated on the magmatic formations of Armenia. In the Azerbaydzhan S.S.R., a five-volume geology of the Republic was produced, including the first compilation on the "Petrography of Azerbaydzhan;" also produced were individual monographs on the petrology and metallogeny of that Republic.

For the Caucasus, as a whole, it became possible to reconstruct the history of its magmatism, and to approach the solution of some important petrologic problems.

Important work in the differentiation of Precambrian metamorphic and magmatic rocks, and in their petrology, was carried

for the Ukraine and the north of the Russian Platform.

In the Urals, a large group of geologists continued their fruitful efforts in obtaining new data on the petrography of metamorphic and magmatic rocks.

The petrographers of Kazakhstan and of other central institutions produced a series of monographs on the geology, petrology and regularities of the volcanic and granitic formations of the Altai and Kazakhstan. These investigations were part of the general geologic study of those regions, and of the task of making exploration maps.

Brought to completion were the works on ultramafic rocks, granitoids, and trap magmatism of the east of our country, constituting a basis for further study of the magmatism of Siberia and Taymyr.

In the Far East, many monographs were published in recent years, shedding light on magmatism and useful minerals associated with the process. Important works on the Maritime Province (Primor'ye) and Khankay, as well as the efforts by the petrographers of the Northeastern Geologic Administration, give an extremely interesting picture of the magmatism in those eastern reaches of our fatherland.

Monograph descriptions of the active volcanoes of Kamchatka, and compilations on the petrography of volcanic rocks, published in recent years, are of considerable value for petrology.

Valuable material had been gathered on the petrogenetic analysis and the systematics of metamorphic rocks and ores, particularly gneisses, secondary quartzites, skarns, and other metasomatic rocks.

The available material and the generalizations that may be made from it permit contemplating the preparation of a series of books summarizing the results in the study of magmatism in various parts of the U.S.S.R.

In progress are such comprehensive works as "Petrography of the U.S.S.R.," for Kazakhstan, the Urals, East Siberia, and the Far East.

Recently there has been a greater establishment of laboratories for radiological determination of the absolute age of rocks.

The application of the absolute age method to the study of the isotope composition of individual elements now makes it possible to correct ideas on the geology of magmatic

formations in some regions of our country, and on the relation between ore formation and petrologic processes.

There are new works on the problems of petrochemistry and geochemistry based on specimens from the Far East, Central Asia, and Caucasus.

The Conference notes a perceptible strengthening in the role played by petrographic studies in the solution of our economic problems.

Alongside these achievements, the Conference recognizes substantial shortcomings in the activity of the petrographers and geologists. The Conference notes a widespread recognition of poorly substantiated concepts of mobile zones, and their usage without consideration of the true geologic conditions.

There also is a lack of coordination in the petrologic and metallogenic investigations carried on in geologically discrete territories which are cut by political boundaries into different administrative regions.

Thoroughness is not always achieved in metallogenic investigations in individual regions, with the petrographers not fully participating in the making of metallogenic and exploration maps.

The solution of some of the most important domestic petrographic problems is often hampered by the scarcity of laboratory facilities and by insufficient experimental work.

The Second Conference recommends that all petrographers take measures towards an elimination of all shortcomings in order to assure the best and most rapid development of petrology.

The Conference believes that the petrographers' efforts, in cooperation with geophysicists and geochemists, should be directed in the next years towards the solution of the complex problem: "Regularities in the development and distribution of magmatic and metamorphic complexes, and their significance in the structure of the earth's crust and in the formation of useful minerals." The immediate attention of the petrographers should be directed to a scientific basis for the search for and the prediction of the occurrence of useful minerals.

Geology and geophysics have made definite strides along the road of knowledge of the crust structure. But such complex problems as the causes and regularities of magmatic development, in time and space (in the

earth's crust), and the relationship between magmatism and useful minerals, are still in the fact-finding stage.

The progress of this effort is hampered chiefly by the following factors:

1) insufficient thoroughness of the geologic and petrologic study of natural associations of magmatic and metamorphic rocks, with inadequate application of most recent methods of the study of matter;

2) insufficient coordination of the geophysical study of the earth's crust with geologic investigations;

3) inadequacy in experimental work utilizing modern techniques, in order to reproduce in the laboratory conditions approaching the natural.

Diverse and complex tasks which stand before modern petrology are:

1) a study of magmatism as an endogenous process in the earth's crust, closely related to the migration and evolution of deep-seated matter within it;

2) a clarification of petrogenetic processes and their significance in the formation of various associations of volcanic and metamorphic rocks and genetically related, useful minerals;

3) the energy aspect of the process, and sources of the internal heat.

A solution of such problems is possible only by a comprehensive method of geophysical, volcanological, and geochemical investigations accompanying the geologic and petrologic studies.

These problems make imperative:

1) a detailed systematic study of all extrusives and their enclosing rocks, including all elements; radioactive, rare, and scattered.

2) setting up of experiments under conditions of temperature and pressure approaching those assumed to exist deep in the earth's crust.

3) a study of mechanical and physical properties of rocks at different temperatures and pressures; likewise essential is a study of the earth's crust with relation to the variation in the isotope composition of a number of elements (lead, strontium, rubidium, argon, and others).

Studies should be continued in:

1) the relationship between tectonics and magmatism, on the basis of regularities in the development of magmatic processes in folded and platform provinces;

2) the petrochemical properties of non-contemporaneous magmatic formations; granitoid, gabbrolike, ultrabasic, alkaline, and the composition of rock-forming minerals and mineral admixtures of these rocks;

3) the features of magmatic processes, depending on the particular conditions of the formation of a given magmatic body; particularly those studies helping our understanding the mechanism of the emplacement and the nature of an intrusion;

4) the relationship between volcanic and plutonic processes, and the role of sub-volcanic processes in the origin and localization of a magmatic ore;

5) the metamorphic regularities and the details of contact-metasomatic processes and ore-contact alterations, in relation with various manifestations of magmatism and tectonic processes; also the effect of the depth of solidification, the form and the composition of magma, and other factors, upon the intensity and composition of contact-mineral formation -- on specific instances of various formations -- and with the consideration of the role of metasomatic processes (in a broad sense) in petrogenesis.

It is also essential to intensify the study of paleo- and neo-volcanism, in order to determine the causes of consecutive formation of volcanics of different composition, of the secular evolution of volcanism and of sedimentary-volcanic occurrences and related deposits.

The Conference deems it expedient:

1) to recommend an application of structural and microstructural analysis in the study of magmatic and metamorphic rocks, in order to facilitate the investigation of the structural position of rocks and their related ore deposits;

2) to take measures towards producing a petrographic terminology with nomenclature and systematics for magmatic and metamorphic rocks.

3) to draw the attention of geologic institutions to the necessity of a comprehensive development of techniques using most recent methods (in physics and chemistry) in the study of the elements of rock and their physical properties.

4) in order to find concrete answers to

stions in petrology, to expedite precise physical and chemical experiments on the nature of deep-seated processes in the earth's crust, inaccessible to direct observations, and important in the formation of intrusive complexes and ore deposits. This requires intensification of experiments with models simulating conditions approaching the natural pressure, temperature, volatiles), including geochemical alterations by metasomatism.

The Conference requests: a) the Presidium of the Academy of Sciences, U.S.S.R. and the Ministry of Geology and Mineral Conservation to organize an interdepartmental petrographic committee, charging it with determining the geologic age of magmatic complexes, petrographic terminology and nomenclature, exploratory drilling into intrusions and other magmatic bodies, and with requesting of a state mapping project for regions of predominantly crystalline rocks; b) the permission of the Presidium of the Academy of Sciences, U.S.S.R. to publish, beginning in 1959, a magazine named "Magmatism and Metamorphism;" c) the Presidium of the Academy of Sciences, U.S.S.R. and the Ministry of Geology and Mineral Conservation to secure the participation of geophysicists and volcanologists in the work of petrographers.

The Conference believes that a more efficient fulfillment of the petrologic tasks, as formulated in this resolution, will be realized by a specialized scientific body, an operative center working out the problems of magmatism and volcanology utilizing a modern technically perfect, laboratory.

The Conference recommends an institution of annual conferences of petrographers from all organizations active in the exploration of individual regions, such as the Kola Peninsula, Karelia, Urals, Caucasus, Kazakhstan, Central Asia, also in the study of individual problems, as for example, alkaline rocks.

The Conference deems it expedient to recommend that the geologic institutes of the several republican academies of science and their affiliates of The Academy of Sciences, U.S.S.R., proceed with the compilation of works on the petrography of their respective territories.

The Conference expresses its gratitude to the Presidium of The Academy of Sciences, UzbS.S.R. for an atmosphere favorable to a wide participation of the Soviet petrographers in its work.

